Forage-Ruminant Workshop
Atelier Fourrages-Ruminants

July 20-21, 2000 / 20 et 21 juillet 2000
Radisson Hotel Winnipeg Downtown

Proceedings of the Symposium
Compte rendu des conférences

Organized jointly by
the Eastern Forage Ruminant Network (EFRN)
and the Western Region Forage/Beef Network (WFBN)

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Foreword / Avant-propos

The Eastern Forage Ruminant Network (EFRN) and the Western Region Forage/Beef Network (WFBN) were created to develop links between researchers, extension specialists and other people involved in forage-ruminant systems. In year 2000, both groups agreed on a joint meeting to broaden the network and to develop cross-links between Eastern and Western Canada.

Participants from across Canada were solicited on a volunteer basis to share research results, review papers or future perspectives related to forage-ruminant systems. The proceedings contain abstracts and papers that were submitted. They represent a snapshot of the variety of work carried out in this area. Our hope is that the meeting will bring about joint projects and facilitate future exchanges.

P. Savoie, G. Bélanger and E. Charmley
Editors of the Proceedings

La région de l'est et la région de l'ouest ont chacune mise sur pied un réseau de chercheurs, de vulgarisateurs et d'autres personnes intéressés par les systèmes fourrages-ruminants. En l'an 2000, les deux réseaux ont décidé de se réunir afin d'accroître les échanges entre les participants des deux régions.

On a sollicité des contributions volontaires sous forme de résumé ou d'article long. Le compte rendu des conférences inclut plusieurs textes qui donnent un aperçu de la diversité des travaux de recherche sur les systèmes fourrages-ruminants. Nous espérons ainsi que la conférence suscitera des projets conjoints et facilitera d'autres échanges à l'avenir.

P. Savoie, G. Bélanger et E. Charmley
Éditeurs du compte rendu

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AA	Alberta Agriculture
AAFC	Agriculture and Agri-Food Canada
BRA	Brandon Research Centre, AAFC
CEF	Central Experimental Farm, AAFC
CHA	Charlottetown Research Centre, AAFC
DPCG	Dairy Producers` Conservation Group, BC
DSRDC	Dairy and Swine Research and Development Centre, AAFC
KAM	Kamloops Research Farm, AAFC
KAP	Kapuskasing Research Farm, AAFC
LAC	Lacombe Research Centre, AAFC
LASE	Lakehill Applied Soil Ecology, BC
LETH	Lethbridge Research Centre, AAFC
MA	Manitoba Agriculture
MCG	McGill University, Macdonald College
MCPA	Manitoba Cattle Producers` Association
MFC	Manitoba Forage Council
NAP	Nappan Research Farm, AAFC
NGPRL	Northern Great Plains Res. Lab., USDA
PAMI	Prairie Agricultural Machinery Institute
PARC	Pacific Agriculture Research Centre, AAFC
SASK	Saskatoon Research Centre, AAFC
SCRDC	Soils and Crops Research and Development Centre, AAFC
SPARC	Semiarid Prairie Agricultural Research Centre, AAFC
TC	Transform Compost, Abbotsford, BC
UBC	University of British Columbia
UOA	University of Alberta
UOG	University of Guelph
UOI	University of Illinois
UOL	University of Lethbridge
UOM	University of Manitoba
UOS	University of Saskatchewan
USDA	United States Department of Agriculture
VPI	Virginia Polytechnical Institute

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Forage-Ruminant Workshop
Colloque Fourrages-Ruminants

Abstracts and full papers
presented on July 20, 2000

Résumés et communications
présentés le 20 juilllet 2000

July 20 / 20 juillet 2000
8:30 to 10:00 a.m.

Session 1: Forage Agronomy and Breeding

Thème 1: Agronomie et amélioration génétique des fourrages

Moderator / Modérateur: Gerald Huebner

IMPROVING THE NUTRITIVE VALUE OF TIMOTHY THROUGH MANAGEMENT AND BREEDING

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Abbreviations:

ADF, acid detergent fiber; **CP**, crude protein; **IVCWD**, in vitro cell wall digestibility; **IVDMD**, in vitro dry matter digestibility; **IVTD**, in vitro true digestibility; **LWR** , leaf to weight ratio; **NDF**, neutral detergent fiber

INTRODUCTION

Timothy (*Phleum pratense* L.) is a widely grown forage species in cool and humid regions of the world including northeastern and northwestern North America, Nordic countries, Russia, and Hokkaido, Japan (Berg et al. 1996). Timothy is the most important perennial forage grass species grown in eastern Canada and it is also grown in most provinces of western Canada. In its area of adaptation, timothy is primarily harvested as hay or silage.

The productivity and nutritive value of timothy is affected by controllable factors such as management practices including harvest date, maturity-based cultivar selection and fertilization, and by uncontrollable factors such as climatic conditions. As well, improvements in yield and nutritive value can be achieved through breeding. The yield potential continues to be a primary selection criterion in timothy breeding, but substantial yield increases through breeding have been difficult to achieve (Berg et al. 1996). For example, in the public testing system of Ontario in 1998, the highest-yielding cultivar exceeds the check, Climax, which was licensed in 1947, by only 9% (Anonymous 1998).

The nutritive value of forage crops decreases with age and phenological development, and traditionally, the nutritive value has been expressed as a function of time or phenological development. This form of presentation is useful in taking into account the effect of chronological age on nutritive value but it does not consider the effect of the environment and management practices (Duru et al. 1997). In this paper, we will consider the changes in nutritive value as a function of the increasing shoot biomass.

This paper presents ways of controlling or improving the nutritive value of timothy through management practices and genetic selection while keeping in mind the importance of yield. Consequently, we will focus on the relationship between nutritive value and yield by first presenting the ecophysiological basis for the decrease in nutritive value with increasing shoot biomass during a growth cycle. In the second part, we will use this relationship to explain the effects of management practices and genetic variability. Nitrogen concentration, DM digestibility, and fibre concentrations are the parameters of nutritive value considered in this paper.

BASIS FOR YIELD/NUTRITIVE VALUE RELATIONSHIP

The growth and nutritive value of forage crops can be described by considering the forage biomass as made of two components (Duru et al. 1997; Lemaire and Gastal 1997). The forage biomass (W) is composed of a metabolic component (Wm) and a structural component (Ws)

$$W = Wm + Ws \quad (1).$$

The structural component is made essentially of cell walls, and as indicated by its name, it is responsible for the structure of the plants. The metabolic component, made of the cellular contents, is responsible for the processes of C assimilation and, therefore, the growth rate (dW/dt) of a forage crop is proportional to the size of the metabolic component at time t:

$$dW/dt = kWm(t) \quad (2).$$

The size of the metabolic component increases with increasing forage biomass and this can be expressed by an allometric function as follows:

$$Wm = k'W^c \quad (3)$$

with $0 < c < 1$. The ontogenic decrease of the proportion of the metabolic component in the forage biomass can be obtained by dividing both sides of equation 3 by W:

$$Wm/W = k'W^{c-1} \quad (4).$$

The N concentration in the forage biomass can be expressed as follows:

$$N = [(Wm \times Nm) + (Ws \times Ns)]/W \quad (5)$$

in which Nm is the N concentration of the metabolic component and Ns is the N concentration of the structural component. Equation 5 can be modified as follows:

$$N = [(Nm-Ns) \times Wm/W] + Ns \quad (6)$$

and by substituting equation 4 into equation 6, we arrive at the following equation:

$$N = k'(Nm-Ns)W^{c-1} + Ns \quad (7)$$

If we neglect Ns in equation 7, it can be seen that the N concentration of the crop depends on the N concentration of the metabolic component (Nm) and the forage biomass (W).
The relationship derived in equation 7 was confirmed in several experiments in which the measured

decrease in N concentration with increasing forage biomass accumulation was described by a model of N dilution:

$$N = aW^{-b} \qquad (8)$$

with the N concentration expressed in percent of DM, the forage biomass expressed in t DM ha^{-1}, and two fitted parameters "a" and "b" (Bélanger and Gastal 2000). The parameter "a" represents the N concentration with 1 t DM ha^{-1}. The parameter "b" represents the coefficient of dilution which describes the pattern of decrease of N concentration with increasing biomass. The parameters "a" and "b" were initially found to be stable (a = 4.8; b = 0.34) over a wide range of pedo-climatic conditions in European countries and for many species and cultivars including alfalfa (*Medicago sativa* L.) and tall fescue (*Festuca arundinacea* Schreb.) (Greenwood et al. 1990). In eastern Canada, the dilution model developed for tall fescue (Lemaire and Salette 1984) adequately identified situations of deficient and non-deficient N nutrition in timothy (Bélanger and Richards 1997), confirming the validity of the relationship between N concentration and DM yield.

The decrease in plant N concentration during growth can therefore be attributed to the increasing ratio of structural to metabolic components during growth (Caloin and Yu 1984; Lemaire and Chartier 1992; Bélanger and Gastal 2000). In other words, the proportion of the relatively N-rich metabolic component decreases during growth, and this explains the decrease in plant N concentration. The crop biomass is a function of the growing conditions and affects N concentration by dilution. The N concentration of the metabolic component, however, is a function of N availability.

A similar approach can be used for digestibility by considering the digestibility of the metabolic (Dm) and structural (Ds) components (Duru et al. 1997). The digestibility of the forage crop (D) can be expressed as follows:

$$D = [(Wm \times Dm) + (Ws \times Ds)]/W \qquad (9).$$

Equation 9 can be modified as follows:

$$D = [(Dm-Ds) \times (Wm/w)] + Ds \qquad (10)$$

and by substituting equation 4 into equation 10, we arrive at the following equation:

$$D = k'(1- Ds)W^{e-1} + Ds \qquad (11)$$

if we assume that Dm is equal to 1.0. Consequently, the digestibility of the forage crop can be seen as the result of the digestibility of the structural component and the crop biomass. The crop biomass is a function of the growing conditions and the digestibility of the structural component is related to the biochemical and histological composition of the structural component.

The nutritive value of a forage crop can also be analyzed as a function of the nutritive value of its component leaves and stems and their proportion in the biomass (Terry and Tilley 1964). The ratio of leaf weight to total weight of harvestable biomass (LWR), a similar concept to the leaf to stem ratio used in several papers, describes changes in the components of plant biomass that have nutritive

implications (Deinum et al. 1968; Lemaire et al. 1989; Bélanger and McQueen 1996). The LWR decreases with increasing shoot biomass. To some extent, leaves can be considered to be equivalent to the metabolic component, and stems equivalent to the structural component. During a regrowth, the increase in shoot biomass results in a decrease in the proportion of leaves and in the metabolic component. The rate of growth will therefore influence the proportion of leaves and metabolic component, and in turn, affect the nutritive value.

MANAGEMENT

Harvest

The decrease in N concentration and digestibility of the DM, and increase in ADF and NDF concentrations with increasing DM yield or maturity during a growth cycle have been reported for timothy in many studies (Kunelius and McRae1986; Berg et al. 1996), and more recently for timothy grown under varying N nutrition (Bélanger and McQueen 1999a), and for early- and late-maturing timothy cultivars (Bélanger and McQueen 1996). In their reviews of literature, Berg et al. (1996) and Thorvaldsson and Andersson (1986) suggested a decline in timothy digestibility of 2 to 7 g kg^{-1} DM d^{-1}. The wide range of reported rates of digestibility decline confirms the need to take into account climatic and environmental conditions. Bélanger and McQueen (1999a) expressed the rate of decline on the basis of thermal time. They reported a decrease of 0.32 g kg^{-1} DM $(°C\text{-}d)^{-1}$ in in vitro true digestibility and an increase of 0.47 g kg^{-1} DM $(°C\text{-}d)^{-1}$ of NDF concentration of timothy grown during spring, under non-limiting N supplies conditions. Hence, delaying harvest by one week with an average daily temperature of 15°C will result in a decrease in in vitro digestibility of 34 g kg^{-1} DM, and an increase in NDF concentration of 49 g kg^{-1} DM.

The rate of decline in nutritive value is less during a summer regrowth than a spring growth cycle (Hidiroglou et al. 1966; Thorvaldsson and Andersson 1986; Bélanger and McQueen 1999a). The rate of decline of LWR and the rate of increase in NDF concentration are also less in summer than in spring (Bélanger and McQueen 1999a), and both are related to a greater growth rate in spring (Bélanger and Richards 1997). This comparison between spring and summer growth cycles illustrates the influence of growth rates on the rate of changes in the proportion of components (leaves or metabolic), and their impact on the nutritive value. Practically, delaying harvest will have less impact on nutritive value during a summer growth cycle than during a spring growth cycle.

The decline in nutritive value, however, is counterbalanced by an increase in DM yield. In selecting a harvest date, producers are therefore confronted with a compromise between the possibility of increasing nutritive value at the expense of DM yield. As indicated above, the expression of the decline in nutritive value with time does not take into account the growing conditions such as temperature, rainfall, and fertility. It has, therefore, a very limited predictive value. The relationship between N concentration and DM yield presented in equation 8 provides the information of the changes in N concentration with increases in shoot biomass when N is not limiting shoot growth. Integrated models of growth and nutritive value can also be used for field specific recommendations

of harvest dates (Gustavsson et al. 1995).

Fertility

Dry matter yield production of timothy is strongly affected by N fertilization (Bélanger and Richards 1997). The effect of N fertilization on the DM digestibility of timothy, however, is the subject of conflicting reports. For example, no effect of applied N on DM digestibility were reported (Calder and McLeod 1968; St-Pierre and Pelletier 1977) while Deinum et al. (1968), Kunelius et al. (1976) and Thorvaldsson and Andersson (1986) in Sweden observed a negative effect of increasing rates of N fertilization on DM digestibility. In both spring and summer, N deficiency increased IVTD and IVCWD, and decreased NDF concentration of forage on the last sampling date corresponding to a normal harvest date for timothy in New Brunswick (Bélanger and McQueen 1999a). The N deficiency increased the proportion of leaves in the biomass, which can explain, for the most part, the positive effect of the N deficiency on the nutritive value of timothy. This positive effect of N deficiency on nutritive value through the proportion of leaves in the biomass, however, was reduced by the negative effect of N deficiency on the nutritive value of leaves (Bélanger and McQueen 1999b).

Timothy primary growth in spring is characterized by a phase of active leaf growth followed by a phase of active stem growth. In the first phase, the nutritive value of the shoot biomass is a function of the nutritive value of the leaves since there are no true stems. During this first phase, N deficiency increases the NDF concentration and decreases its digestibility with the overall effect of decreasing DM digestibility of leaves (Bélanger and McQueen 1999a). The second phase of timothy spring growth is characterized by the presence of leaves with an increasing biomass of true stems produced by the elongation of internodes, and this results in a reduced proportion of leaves. When the proportion of leaves was taken into account, there were still differences in nutritive value which had to be related to the leaves and/or stems (Bélanger and McQueen 1999a).

These results on the effect of N fertilization on the digestibility of timothy can be explained by considering the ecophysiological basis of the relationship between digestibility and growth. We previously indicated that the digestibility depended on the digestibility of the structural component, and the crop biomass. The reduced digestibility of timothy with increased N fertilization was, in part, the result of increased growth (Bélanger and Richards 1997) and a concomitant decrease in the proportion of leaves. Assuming that the leaves are equivalent to the metabolic component and stems are equivalent to the structural component, we can conclude that N fertilization modified the proportion of metabolic and structural components. The equivalence between leaves and metabolic component, however, has its limitations for timothy and other grasses (Duru et al. 1997). The leaves of timothy are very active in C assimilation but they also have a structural component. Bélanger and McQueen (1999b) indicated that N fertilization affected the structural component of the leaves by decreasing the NDF concentration and increasing the cell wall digestibility.

Nitrogen fertilization can increase the N concentration of timothy (MacLeod and MacLeod 1974; Guertin et al. 1979). The effect of N fertilization on the N concentration of timothy combines a direct

positive effect on the N concentration of the metabolic component, and an indirect negative effect by a greater N dilution in a greater biomass produced. Consequently, the increase in N concentration with increased N fertilization and availability is often relatively small. This is the case primarily when soil N availability is limited, and N fertilization increases DM yield. In situations when soil N availability is high, N fertilization may have no effect on yield but it may increase N concentration (Bélanger and Richards 1997), and the presence of nitrates in the crop (MacLeod and MacLeod 1974; Guertin et al. 1979; Kline and Broersma 1983; Ziadi 2000).

Cultivars with different maturity

Timothy cultivars have been selected to mature at different rates during primary growth. Ear emergence or heading of early- and late-maturing cultivars of timothy grown in the same environment may vary by as much as 3 wk in the spring (Mika 1983; Surprenant et al. 1993). Early-maturing timothy cultivars are less digestible than late-maturing cultivars on a given date (Mowat et al. 1965; Kunelius 1990; Bélanger and McQueen 1996). When compared at the same growth stage, however, early-maturing cultivars have a greater nutritive value than late-maturing cultivars (Bélanger and McQueen 1996; Jefferson et al. 2000). The rate of decline in DM digestibility is greater for early-maturing cultivars than for late-maturing cultivars (Koch 1976; Mika 1983; Bélanger and McQueen 1996). Early-maturing cultivars have higher growth rates than late maturing cultivars (Bélanger and Richards 1995), and this affects the change in LWR. Differences in DM digestibility and NDF concentration between cultivars differing in maturity, however, are not related only to the proportion of leaves in their biomass. Leaves and stems of early-maturing timothy cultivars have a greater nutritive value than those of late-maturing cultivars (Bélanger and McQueen1997; Jefferson, pers. comm.). The difference between early and late-maturing cultivars, however, is greater for leaves than stems.

These differences in nutritive value between early- and late-maturing timothy cultivars confirm the role of the proportion of leaves in the biomass in nutritive value. It also confirms that leaves cannot be considered only as a metabolic component. Leaves have a structual component which can be affected by the growing conditions.

BREEDING

Genetic variability for individual traits

Genetic increases in some measure of digestibility have been documented in new cultivars of at least seven forage crops (Casler and Vogel 1999). In timothy, genetic variability was reported for crude protein (CP) and in vitro dry matter digestibility (IVDMD) (Berg and Hill 1983), and IVDMD decline (McElroy and Christie 1986b). Surprenant et al. (1990b) observed significant variation among half-sib families for CP, IVDMD, NDF, and ADF. Surprenant et al. (1990a) also observed significant variation for DM digestibility, CP, ADF, and NDF following one cycle of divergent phenotypic selection for CP, digestibility and digestible yield. No North American cultivar has been

selected for digestibility (Berg et al. 1996). Cultivars differences for IVDMD have been reported, although some are confounded with maturity effects (Mason and Flipot 1988). McElroy and Christie (1986b) concluded that DM digestibility at heading and relative decline in DM digestibility were not associated, and that, consequently, it should be possible to identify large number of plants which are highly digestible at the heading stage, but whose digestibility decline with advance in maturity is 20-25% less than that of the parental population.

Improvements in timothy digestibility can only be achieved by reducing the proportion of the structural component, or by increasing the digestibility of the structural component. If we assume that leaves are equivalent to the metabolic component, digestibility could be improved by selecting genotypes with a greater proportion of leaves. The other option is to select genotypes with a greater digestibility of the structural component which we can assume to be the stems (Durand and Surprenant 1993). In alfalfa, there is a negative relationship between the length of stems and digestibility. Shorter stems are more digestible because of a greater proportion of leaves on those stems and because of a greater nutritive value of the stems themselves (Lemaire et Allirand 1993). Selecting for shorter stems, however, might result in reduced yield. Breeding efforts to improve timothy digestibility should therefore focus on improving the digestibility of stems by modifying their biochemical and histological composition. The focus on stems in timothy is also justified by the high proportion of stems at harvest which can be as high as 70% of the forage yield.

The improvement in forage N concentration can be achieved by increasing the N concentration of the metabolic component or by increasing the proportion of the metabolic component to the structural component. The work of Brégard et al.(2000) has shown that a population of timothy selected for high N concentration had a greater proportion of leaves that a population selected for low N concentration. This confirmed that improvements in N concentration can be achieved by increasing the proportion of the metabolic component considered to be the leaves in this case. The NDF or cell wall concentration (structural component) of the population selected for high N concentration was also smaller (Brégard et al. 1999). The other option is to increase the N concentration of the metabolic component which is a function of N availability and N uptake efficiency. For a given N availability, the N concentration of the metabolic component will be increased by selecting genotypes with a greater N uptake efficiency.

Genetic variability for yield/quality relationship

It is well accepted that forage nutritive value characteristics such as N concentration and DM digestibility decrease with increases in DM yield (Bélanger and Richards 1996; Bélanger and McQueen 1999a; Casler and Vogel 1999). This suggests that cultivars with improved DM yield may have lower nutritive value. Hence, the relationship between DM yield and nutritive value should also be taken into account when comparing genotypes with the objective of improving both DM yield and nutritive value.

Genetic variability for DM yield and N concentration was found among 40 half-sib families of timothy grown under field conditions (Michaud et al. 1998). Some families yielded as much as 20%

more than the reference cultivar Champ. Furthermore, the variability in N concentration among the high yielding families indicated a genetic variability for the relationship between DM yield and N concentration, and the possibility of increasing both DM yield and N concentration. Differences in the relationship between DM yield and N concentration were also observed for two populations selected for high (N+) and low (N-) forage concentration (Brégard et al. 2000). The forage DM yield of N- was greater than that of N+ but, at an equivalent forage DM yield, N+ had a greater N concentration than N-. Our results on timothy confirm the possibility of improving nutritive value while maintaining forage yield, and this is in agreement with the conclusions of Casler and Vogel (1999).

Interaction with management

Significant genotype x environment interactions for forage quality were reported by Surprenant et al. (1993) and McElroy and Christie (1986a). Brégard et al. (2000) also observed that the ranking of timothy genotypes for DM yield differed under limiting and non-limiting conditions. This suggests that genotypes should be tested under a wide range of environmental conditions. We suggest that the relationship between forage yield and nutritive value should be the basis for the analysis of data from multi-environment trials. As we discussed above, growth rates and therefore yield affect the proportion of the metabolic and structural components, and ultimately nutritive value. The nutritive value of genotypes from multi-site trials should be compared at a similar level of yield. By doing so, we speculate that we could remove a significant proportion of the environmental variability. Julier and Huyghe (1997) used this approach to account for the effect of growth and cultivars on alfalfa digestibility in a multi-site trial.

CONCLUSION

In this review paper, the nutritive value of timothy is considered in relation to the accumulation of shoot biomass, and by assuming that the shoot biomass is made of two components: metabolic and structural. The decrease in the proportion of the metabolic component with increasing shoot biomass reduces the nutritive value of timothy. The nutritive value is also affected by the N concentration of the metabolic component, and by the digestibility of the structural component. The effect of harvest management, fertility and cultivars on the nutritive value of timothy can be analysed in terms of the indirect effect through increased shoot biomass and the change in the proportion of the metabolic and structural components, and the direct effect on each component.

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LOOKING FOR A LEGUME-SHRUB MIXTURE FOR OPTIMUM FORAGE PRODUCTION

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ABSTRACT

Late season grazing decreases the cost of beef production in southwestern Saskatchewan. This grazing system can be improved by utilizing legume and native shrub species, which maintain higher nutritional quality in the fall. To realize the systems full potential we need a better understanding of optimum mixtures of legumes and shrubs. A field and a greenhouse pot study were initiated to optimize mixtures of legumes and shrubs for economical pasture production. The first goal was to obtain better understanding of synergy from combinations of legumes and native shrubs. The second goal was to estimate the changes in quality of soil caused by growing legumes and shrubs in monocultures or mixtures. Legume species studied were: alfalfa (*Medicago sativa*), purple prairie clover (*Petalostemon purpureum*) and american vetch (*Vicia americana*); shrubs were: winterfat (*Krascheninnkovia lanata*) and salt bush (*Atriplex nuttallii*). All field plots were rototilled before transplanting legume and shrub seedlings. Treatments consisted of five monocultures, six combinations and a control. Data on plant mortality, forage production, forage quality, soil moisture and changes in soil quality parameters will be discussed in relation to the optimization of forage production in the region.

Keywords: Legume, native shrub, forage production, forage quality

INTRODUCTION

Late season grazing has been considered as a method of decreasing the cost of beef production in southern parts of western provinces of Canada. The quality of available forage in fall and winter generally restricts the grazing season. Grasses are usually the main forage source even though they are not the only source of herbage during that period. Research has shown that nutritional value of native shrubs (Dietz 1972), and, shrubs and forbs (Smoliak and Bezeau 1967; Cook 1972) is higher than for grasses. Cost of beef production can be reduced by up to 56% by overwintering cattle on winter pasture (J. Graham, pers. comm.). Thus, it would be beneficial for livestock producers to have a high quality, late season grazing with low cost of input. One method of improving late season grazing is to utilize native shrub and legume species which maintain higher nutritional quality in the fall. The development of a potential forage source with these species, one requires a clearer understanding of optimum mixtures of legumes and shrubs.

In recent years, two native shrubs of southwestern Saskatchewan (winterfat and saltbush) have been gaining considerable attention from both producers and researchers. Winterfat has been recommended as a salt and drought tolerant (Van Dersal, 1938; Stubbendieck et al. 1986) and highly palatable nutritious native shrub (Romo et al. 1995; Abouguendia 1998). This species provides excellent forage to livestock and wildlife in this region, and is being used for wildlife habitat reclamation (Bai et al. 1998). Winterfat retains enough protein and minerals for livestock feeding on winter range (Smoliak and Bezeau 1967). There is also considerable interest in using this shrub for restoration and improvement of rangelands on the Canadian Prairies (Hou and Romo 1997).

Like winterfat, similar nutritional data are also available for saltbush (Smoliak and Bezeau 1967; Banerjee et al. 1999). Saltbush can also be used as winter forage by livestock and is fairly palatable to cattle (Smoliak et al. 1993). There are number of cultivars of southern species available from the United Sates but we have observed that they lack the appropriate Canadian winter hardiness. Although saltbush is found on badlands and eroded soils throughout the Canadian Prairies, the most productive saltbush shrubs are found on south facing slopes in sandy soils with cobble stones in association with blue grama grass (Banerjee et al. 1999). However, Le Houerou (1992) reported that in spite of a number of constraints in their establishment, management and utilization, the planting of saltbush appeared to be one of the best ways to rehabilitate desertified areas and restore them to production.

The native legumes, American vetch and Prairie clover, and alfalfa are known to have high nutritional value. American vetch is a highly palatable forb and prairie clover is also an important palatable component of prairie hay (Hermann 1966). In the Canadian Prairies, popularity of alfalfa as forage crop has also been increasing and it is found growing in southwest Saskatchewan under natural conditions. Growing pure alfalfa alone is not well accepted among producers due to fear of bloat in cattle. There is a need for a proper mixture of forages with high yield and low production cost which decreases the risk of bloat. A pasture with mixed species such as a shrub and a legume may be suitable for this purpose. A pasture with the ideal mixture would produce higher forage and livestock yield as well as provide late season grazing at low production cost.

In many countries, growing trees and shrubs together for improving soil fertility has been gaining considerable attention. In central Africa, where rainfall is limited, various experimental results indicated that soil fertility, especially N supplying capacity, has been increasing and higher crop yields were obtained following different shrub fallows (Barrios et al. 1996a, 1996b; Buresh and Tian 1996). This enhancement of soil quality may be due to the increase of soil organic matter quantity and quality. Although this important aspect of soil quality has never been investigated in Saskatchewan, there is tremendous potential for growing native shrubs with legume to improve soil quality and/or soil health in the region.

The long-term objectives of this investigation were to optimize mixtures of legumes and shrubs for economical production of pasture, to extend the grazing season, to obtain better understanding of synergy from the combination, to further improve their forage quality, and to monitor the changes in soil quality caused by growing them together in pasture land.

MATERIALS AND METHODS

Field Plot Study

A field study was initiated to optimize mixtures of legumes and shrubs for pasture in South Farm, Swift Current, SK. Legumes species studied were: alfalfa (*Medicago sativa*), purple prairie clover (*Petalostemon purpureum*) and american vetch (*Vicia americana*); shrubs were: winterfat ((*Krascheninnkovia lanata*, formerely known as *Ceratiodes lanata* or *Eurotia lanata*) and salt bush ((*Atriplex nuttallii* or *Atriplex gardneri*). Treatments were applied to plots arranged in a randomized complete block design. The total number of treatment plots was forty eight. Each plot was 9 m x 3 m with two rows of legume and/or shrub transplanted with well established Russian wildrye in rows on either side of legume/shrub combinations. Before transplanting (May 29, 1998) shrub seedlings or seedling legumes, all plots were rototilled in 2 m wide strip to eliminate Russian wildrye. Treatments consist of five monocultures, six combinations and a control; with four replications. The treatments were: i) Alfalfa (Alf), ii) Purple Prairie Clover (Pr Cl), iii) American Vetch (Vetch), iv) Winterfat (Wf), v) Saltbush (Sb), vi) Alfalfa + Winterfat (Alf + Wf), vii) Alfalfa + Saltbush (Alf + Sb), viii) Purple Prairie Clover + Winterfat (Pr Cl + Wf), ix) Purple Prairie Clover + Saltbush (Pr Cl + Sb), x) American Vetch + Winterfat (Vetch + Wf), xi) American Vetch + Saltbush (Vetch + Sb), and, xii) Control - no seedlings in strip.

Plant mortality, total forage production, forage quality, soil moisture and changes in soil quality parameters were monitored. Initial soil characterization was done (Table 1). Soil moisture content was initially monitored every two weeks and later, on a monthly basis by Time Domain Reflectometer (TDR).

Greenhouse Pot Study

Soils were collected from the same site as the field study (South Farm, Swift Current). A simulated pot study was conducted in the greenhouse (16 hour photoperiod, 8 hour dark) using the same 12 treatments as the field study. However, the number of replications per treatment was three to give a total number of thirty-six pots for the experiment. Each pot contained 2 kg of soil. Shrubs and legumes were transplanted into the appropriate pots in the last week of August 1998. The seedlings came from the same seed lots as the field experiment. Four plants were transplanted into each pot. For monocultures, each pot contained 4 plants of a single species and for the mixture treatments, 2 plants per selected species. Plant biomass was measured as fresh and dry weights at five consecutive harvests. At the fifth harvest, soils were destructively sampled to assess the changes in the soil parameters.

Soil and Plant Analyses

Total C and N in soil were determined by an automated combustion technique (Carlo Erba™, Milan, Italy). Soil organic C was determined by the same combustion method after removal of carbonates with phosphoric acid (Campbell et al. 1995). Soil NH_4-N was determined by the method of Gentry and Willis (1988). Soil NO_3-N, extractable P and extractable K were determined using the technique

of Hamm et al. (1970), and extractable S was determined by the method of Hamm et al. (1973). For plant analysis, oven dry plant materials were digested using a digesting mixture (H_2SO_4/Se/Na_2SO_4). Total N was analysed by AOAC (1984) method and total P was measured by using Varley (1966) technique. Crude protein concentration in plant was calculated by the factor (total N x 6.25). Protein yield and P content were calculated on the oven dry biomass weight basis.

Statistical Analyses

Statistical analyses of the data were performed by the analysis of variance and means comparisons of the treatment effects. Data were analysed using SAS statistical software (SAS Institute, Inc. 1989). Where appropriate, as a significant F value was obtained, least significant difference (Fisher LSD) was determined.

RESULTS AND DISCUSSION

Establishment and growth of legume/shrub plants in the field at different growth stages were visually observed. Although the initial establishment of the shrub/legume plants were acceptable, by fall, vetch and saltbush were struggling to grow. In general, growth of the plants was poor in the initial year of the field study most probably due to the very dry growing season (data not shown). Vetch was completely dormant and growth of saltbush was poor. As a result, biomass determination was not done. Although it was too early to find any significant observation, there was only visual indication that the plant mixtures might be growing better than the monocultures.

Establishment and growth of shrub/legume plants in the pots at different growth stages were visually observed. In the pot study, based on the five bulked cuts, the mixture treatments had significant ($P \leq 0.001$) effects on fresh plant biomass production. Combination treatments in general produced more biomass than the monocultures (Figure 1). The Alf + Wf ($P \leq 0.001$), Alf + Sb ($P \leq 0.01$), Pr Cl + Sb ($P \leq 0.05$) and Vetch + Wf ($P \leq 0.01$) combinations significantly produced more biomass than their respective monocultures combined biomass. A multi-year experiment carried out in southwest Saskatchewan indicated that the yield from the mixture of legume and grass was always higher than growing grass alone (Leyshon 1978). Enhanced growth of the grass could be related to the increased available N supplied by the legume. Similar synergistic phenomenon might have occurred between the legume (alfalfa) and the shrubs (winterfat and saltbush). In the Alf + Wf and Alf + Sb treatments, production of alfalfa was increased to the extent that the total production of the combinations were higher than the monocultures even though the production of winterfat and saltbush have been decreased (Figure 1). This might have been due to light competition in the smaller pot surface area because of the more upright vigorous growth of alfalfa compared to the relatively shorter and bushier type plants, winterfat or saltbush. In addition, only Alf + Wf and Alf + Sb treatments showed positive or no negative significant ($P \leq 0.05$) impact on the biomass production on oven dry weight basis (Figure 2). Alfalfa growth in Canadian Prairies is often limited by low soil moisture contents. Waddington and Steppuhn (1996) and Steppuhn and Waddington (1996) reported a 40% increase in alfalfa production when soil moisture was increased using tall wheatgrass windbreaks that trap snow and decrease evapo-transpiration. The shrubs, winterfat and

saltbush, may also serve similar purpose as the tall wheatgrass windbreaks in a field situation. Thus, growing a mixture of shrub (Wf or Sb) and legume (Alf) has the potential to maximize the mutual benefit, as legume provides available N to the shrub and the shrub conserves moisture. On the other hand, the Pr Cl + Wf and Vetch + Sb treatments did not significantly ($P \leq 0.05$) enhance biomass production compared to the combined production of their respective monoculture treatments (Figure 1). The Pr Cl + Sb and Vetch + Sb combinations produced more shrub (saltbush) compared to the respective legumes. Although the production was not as high as Alf + Wf or Alf + Sb combinations, these observations might have a bearing on the composition of the forage stands (Figures 1 and 2). Thus, these data indicate that there might be potential benefits of growing Alf + Wf or Alf + Sb as the legume-shrub combinations.

Forage quality (protein yield and P content) was increased or nearly maintained at the same level in the Alf + Wf and Alf + Sb treatments compared to the combined forage quality of their respective monoculture treatments (Figures 3 and 4). Both protein yield and P content were increased significantly ($P \leq 0.01$) in the Alf + Wf combination where as in Alf + Sb combination protein yield was increased slightly and no significant change was observed in P content. The combinations therefore may provide enough protein and phosphorous for livestock, but less crude fibre than do principal grasses of comparable growth stage (Smoliak and Bezeau 1967). Thus, they may be used as a potential winter pasture forage which will help in extending the grazing period, resulting in decreased operational costs and greater returns to the livestock producers (Adams et al. 1996). However, no significant changes were found at this time in soil quality parameters measured by growing legumes and shrubs in mixtures in pots (Table 2). This is most probably due to the limited number of plants on each pot and duration of the investigation. In a long-term field experiment we might find different scenarios for the changes in soil quality parameters. Nonetheless, this pot study indicated that alfalfa–winterfat /alfalfa-saltbush mixtures might have the potential to increase forage production as well as forage quality.

CONCLUSION

The study indicates that a pasture with a mixture of legume and shrubs (Alf + Wf and/or Alf + Sb) can potentially provide diversified forage source, extended grazing periods, and produce higher yields than when grown separately with enhanced or similar forage quality. However, long-term field study is needed before the true benefit can be established satisfactorily.

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Table 1. Physical and chemical characteristics of South Farm soil at the legume-shrub study site.

Characteristics	Analysis
Texture	Sandy loam
Sand (%)	65.4
Silt (%)	21.1
Clay (%)	13.5
pH	6.61
EC (dS^{-1})	0.54
Total C ($g\ 100g^{-1}$)	1.93
Organic C ($g\ 100g^{-1}$)	1.84
Organic C as % of Total C	95.13
Total N ($g\ 100g^{-1}$)	0.2
NH_4-N ($\mu g\ g^{-1}$)	2.95
NO_3-N ($\mu g\ g^{-1}$)	1.76
C : N	9.84
Extractable P ($\mu g\ g^{-1}$)	5.8
Extractable K ($\mu g\ g^{-1}$)	457.54
Extractable S ($\mu g\ g^{-1}$)	3.67

Table 2. Soil parameters[z] after the 5th harvest in the legume-shrub pot study.

Treatment	Total C ($g\ 100\ g^{-1}$)	Organic C ($g\ 100\ g^{-1}$)	Organic C as % of total C (%)	Total N ($g\ 100\ g^{-1}$)	C : N
Control	1.58 ± 0.10	1.55 ± 0.07	98.17 ± 2.03	0.16 ± 0.01	9.67 ± 0.18
Alfalfa (Alf)	1.54 ± 0.04	1.51 ± 0.05	98.26 ± 0.80	0.15 ± 0.01	9.88 ± 0.47
Winterfat (Wf)	1.69 ± 0.11	1.66 ± 0.11	98.02 ± 0.71	0.16 ± 0.01	10.40 ± 0.12
Saltbush (Sb)	1.99 ± 0.31	1.89 ± 0.24	95.41 ± 3.19	0.17 ± 0.01	11.30 ± 0.94
Alf + Wf	1.62 ± 0.10	1.58 ± 0.12	97.49 ± 1.25	0.16 ± 0.01	10.10 ± 0.42
Alf + Sb	1.71 ± 0.06	1.66 ± 0.10	97.02 ± 3.16	0.16 ± 0.01	10.20 ± 0.96

[z]Values are mean of four replications ± Standard deviation

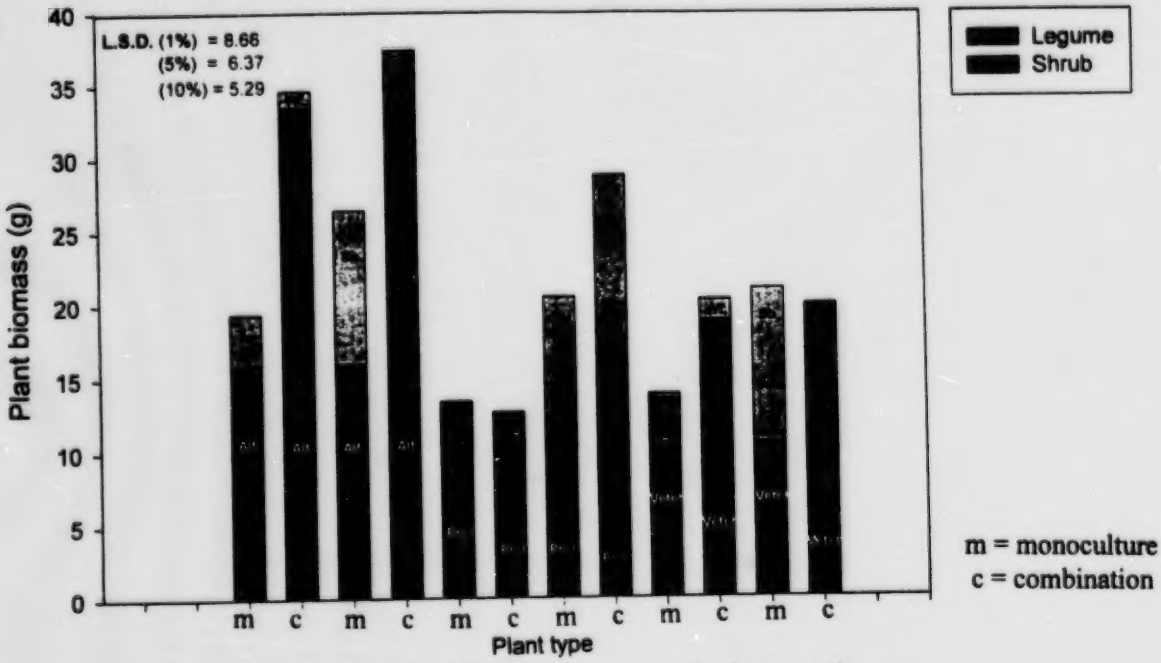

Figure 1. Fresh plant biomass in legume-shrub pot study

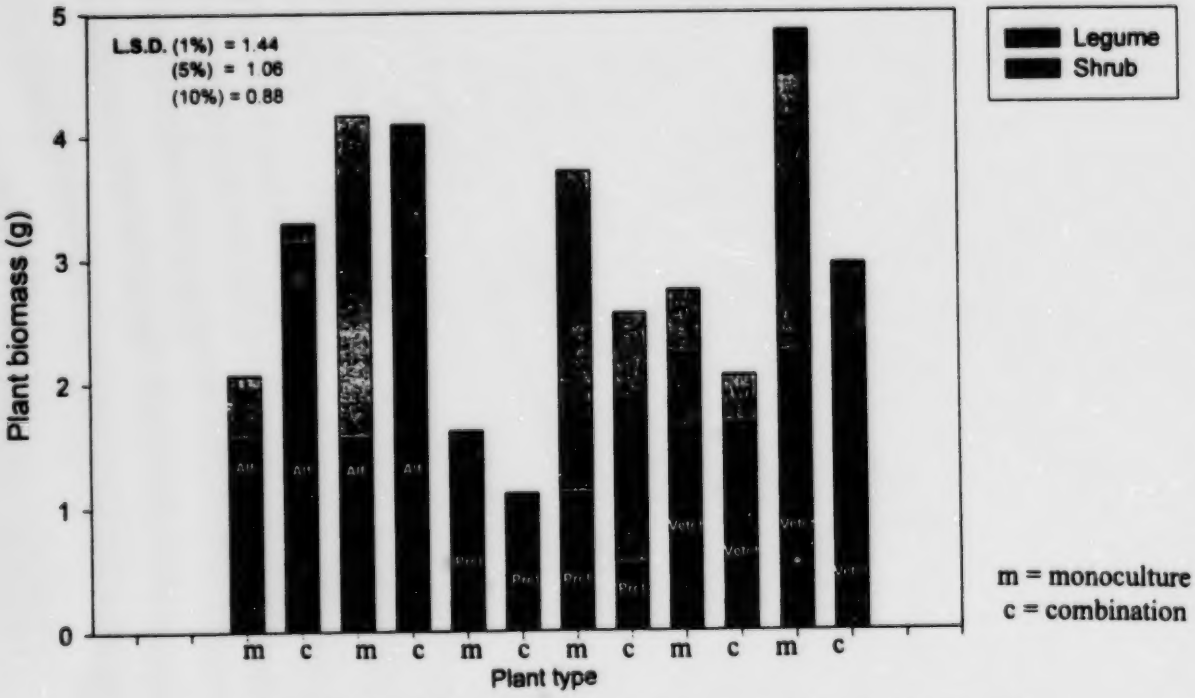

Figure 2. Ovendry weight of plant biomass in legume-shrub pot study

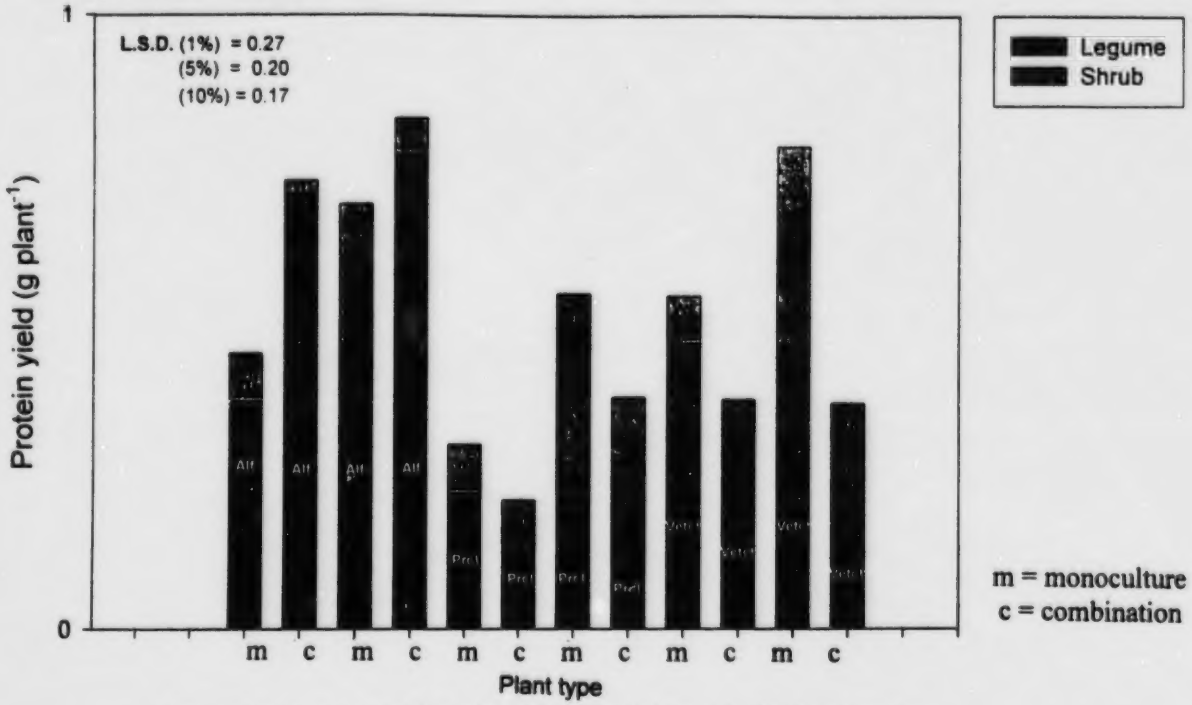

Figure 3. Protein yield in plant biomass in legume-shrub pot study

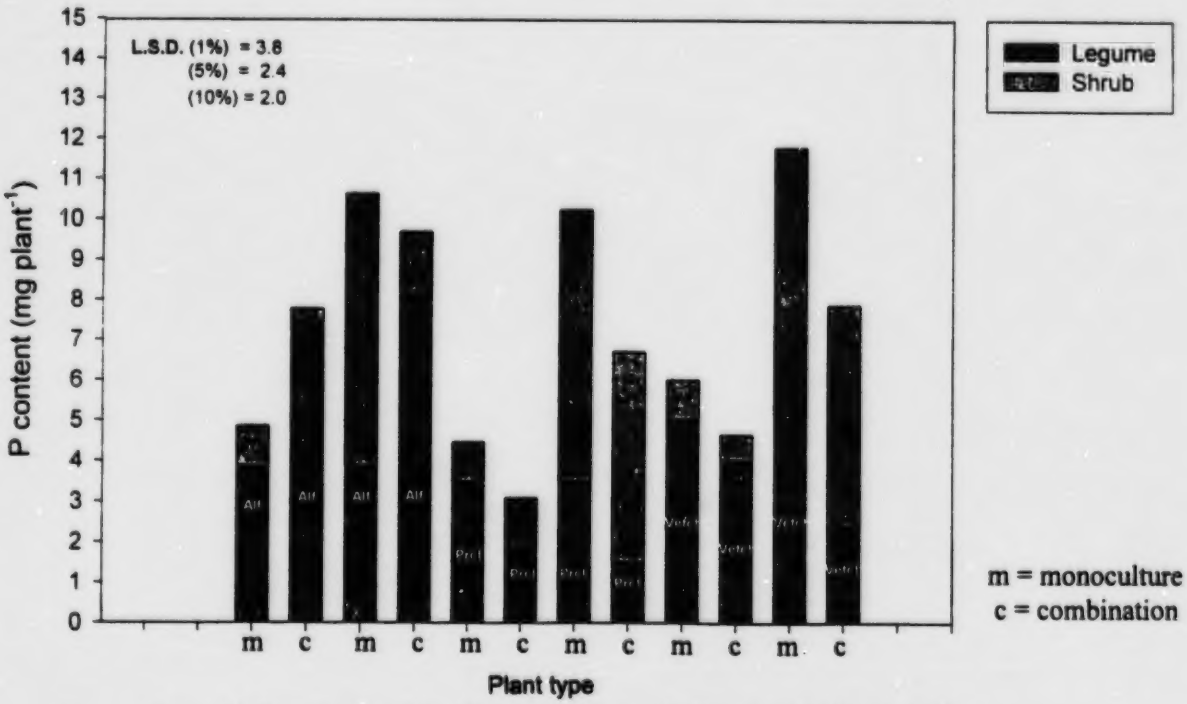

Figure 4. Phosporus content in plant biomass in legume-shrub pot study

RESPONSE OF FORAGE CROPS TO ANOXIA DURING WINTER

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INTRODUCTION

The formation of an impermeable ice sheet over perennial plants during winter induces modifications of the atmosphere around the plants. The resulting anaerobic conditions can affect the winter survival of economically important forage crops. The differential sensitivity of alfalfa, timothy, orchardgrass and red clover exposed to a progressively developing anoxic stress was assessed under simulated winter conditions as well as in field experiments.

EXPERIMENTS

In a first experiment, the four species were exposed to a progressively developing anoxic stress by enclosing potted plants in gas-tight bags in late fall and exposing them to simulated winter conditions in an unheated greenhouse. Furthermore, four pots filled only with soil were used to assess the contribution of the microflora to atmospheric changes. Gas composition in bags, regrowth potential and biochemical components related to cold acclimation and anoxic metabolism were measured at different intervals after the initiation of treatments. Anoxic conditions (0% O_2) were reached after 60 d of enclosure for orchardgrass, alfalfa and red clover, 80 d for timothy and 106 d for bare soil. A large proportion of the O_2 consumption was attributable to the soil microflora activity. Damages were observed and the regrowth was impaired in the most sensitive species only when the O_2 was completely consumed and the CO_2 concentration reached 15%. Based on plant regrowth, the sensitivity ranking of the species was: red clover and orchardgrass > alfalfa > timothy.

In the field experiments, an impermeable ice cover was simulated by covering plots ($3m^2$) of alfalfa, red clover, orchardgrass and timothy with gas-tight plastic sheets at the end of November, just before the onset of a permanent snow cover. The control plots were left uncovered. Gas sampling systems and thermocouples were installed in each plot. The concentrations of O_2 and CO_2 at the soil-atmosphere interface were measured on six occasions during the winter while soil and air temperatures were monitored hourly. Throughout winter, the O_2 concentration under impermeable covers decreased progressively from ~21 to 2-5 % whereas the CO_2 concentration increased from ~0.03 to 4-8 %. For all species, forage yield measured twice during the following summer was unaffected by the hypoxic conditions reached at the end of winter. For both gases, the extreme concentrations of 0% for O_2 and 15% for CO_2 that were observed under simulated winter conditions

were not reached in the field study. There are, however, indications that changes in the atmospheric composition under gas-tight covers may vary with the soil organic matter content. For that reason, a field experiment was undertaken in which the soil C content was increased by applying an organic amendment (54t/ha) one week prior to installing the plastic sheets. The amendment increased the rate of O_2 depletion and CO_2 production as compared to control plots.

CONCLUSION

We conclude that the presence of a lasting impermeable cover in winter may affect winter survival and yield of major forage crops. The development of anoxic conditions under impermeable covers such as ice depends on many factors including soil C content, microflora activity as well as plant metabolism.

USE OF MOLECULAR MARKERS IN BREEDING AND GENETIC ANALYSIS OF BROMEGRASSES

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ABSTRACT

Molecular markers are being used in forage grass improvement projects to determine genetic diversity, differentiation of related species, assessment of phylogeny and selection of individuals with superior agronomic characteristics. At the Saskatoon Research Centre we are using RAPD and AFLP markers to determine genetic relatedness of hybrid bromegrass to its parental meadow and smooth bromegrass populations, identify genetic markers associated with rhizome production and verify hybridity of progeny from meadow and smooth bromegrass crosses. Individuals of meadow, smooth and hybrid bromegrass have been genotyped at 43 polymorphic RAPD and 84 AFLP loci. Markers were generally present in different frequencies in each population, but a few were species specific. Cluster analysis showed three distinct groups representing the two parental populations and the hybrid population. The hybrid population had the highest within population variation, followed by meadow and then smooth bromegrass. The hybrid population was genetically intermediate to the parental species, but closer to smooth bromegrass, reflecting the selection criteria used in its development. Species specific RAPD marker and other markers have been used to detect plants that resulted from selfing when smooth and meadow bromegrass are crossed to synthesize new hybrids. Morphological data in conjunction with RAPD markers were used to correctly identify hybrid individuals. To facilitate the development of new lines of reduced rhizome producing smooth bromegrass crosses have been made between rhizome producing smooth bromegrass, and non-rhizome producing plants. F1, F2 and BC1 progeny of these crosses will be phenotyped and fingerprinted to determine markers associated with rhizome production.

DEVELOPMENT OF HYBRIDS BETWEEN SMOOTH AND MEADOW BROMEGRASS FOR USE AS DUAL PURPOSE HAY/PASTURE SPECIES

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ABSTRACT

Hybrid populations between meadow and smooth bromegrass (*Bromus riparius* Rehm. X *B. inermis* Leyss.) have been developed at the Saskatoon Research Centre. Two populations, S9197 and S9073, were selected for characteristics such as vigor, uniformity of growth, reduced creeping habit, floret fertility and seed yields, and are several generations removed from the original hybrid population. These lines show many characteristics intermediate to the parental species. Two other populations, S9183 and S9356, were selected for similar characteristics from backcross populations (*B. inermis* X (*B. riparius* X *B. inermis*)). The latter two lines, since they have the smooth brome cytoplasm, resemble this species more in morphological characteristics. Of the four hybrid populations, S9197 has been most extensively evaluated and is being released as a cultivar in 2000. S9197 is tall, reduced creeping relative to smooth brome, and is intermediate in regrowth and frost tolerance. It is lower in fibre than the parental species in vegetative growth and similar at later stages of maturity. In regional forage trials, S9197 produced hay yields 96% of smooth brome and 106% of meadow brome. Hay yields were particularly lower than smooth brome in the moister black and grey wooded zones, but they were equal in the dark brown and brown soil zones of western Canada. Pasture clipping trials have shown yields of S9197 to be superior to smooth and similar to meadow brome. In grazing trials at Swift Current, S9197 produced as much, or more, beef per unit area over a three year period than either smooth or meadow brome. These hybrid populations show considerable potential as dual purpose hay/pasture grasses.

STRATEGIES FOR CLOVER BREEDING IN CANADA

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ABSTRACT

Clover species, primarily red and white, are widely adapted and productive forage legume species in most temperate regions in the world. In Canada their main limitation is the fact that all known varieties are short lived. The poor persistence is attributed to three main factors: the nature of the species, poor winter hardiness, and/or their susceptibility to numerous root and crown diseases. To date, specific selection techniques for identifying genotypes with superior persistence have not been successful in significantly improving the general adaptation and/or the long-term persistence of this species. Breeding efforts on these species have been reduced significantly in the past decade. Only one public research centre currently funds a breeding research program, the Crops and Livestock Research Centre of AAFC in Charlottetown, P.E.I. Research at other centres with short-term funding is currently developing improved populations but their work is totally restricted to one species, red clover (*Trifolium pratense* L).

INTRODUCTION

The objective of this presentation is to review current breeding efforts in Canada for red clover and white clover as well as identify a strategy for utilizing current resources for future research and breeding for each species.

Red clover

In the absence of direct selection techniques, many strongly believe that natural selection in the regions intended to grow the newly developed varieties is the only effective and proven technique for maximizing persistence. In fact, natural selection is the main technique utilized for enhancing persistence while developing new cultivars with enhanced persistence at our centre during the past twenty years. Research efforts continue in developing techniques for identifying genotypes with superior persistence. Two cycles of screening for resistance to low temperatures were completed, however, these efforts did not result in any improvement in winter hardiness, persistence or yield (personal communication, Christie 1997). Early results of utilizing morphological markers have shown that stem colour was highly associated with freezing tolerance under controlled environment

assessment (Nowak and McLean, unpublished data). Selection for increased herbage yield has been accomplished by evaluating red clover synthetics composed of genotypes identified from old stands with no evidence of root rot diseases (Choo et al. 1994; Christie et al. 1997; Christie and Martin 1999; Martin et al. 1999).

Future work in Canada will continue to utilize natural selection for winter hardiness and persistence but new studies have been initiated to investigate: a) the possibility of developing germplasm with improved general adaptation (persistence and yield) to several regions across Canada; b) assess the role of selected disease resistance in improving general adaptation; c) establish a cause and an effect between morphological markers and long-term persistence.

White Clover

White clover is an important legume species in eastern Canada. Currently recommended varieties, mostly from Europe, do not persist in long-term cropping systems. New cultivars with improved winter hardiness are required for inclusion in pasture based cropping systems. Despite the fact that naturalized forms of white clover appear as volunteers in old or newly seeded pastures, their presence never achieved the required levels to ensure a productive stand. In previous studies, evaluated ecotypes of white clover collected from old pastures in Atlantic Canada have shown considerable variability for useful characteristics (Frazer 1987; Papadopoulos et al. 1997; Caradus and Christie 1998; Christie, unpublished data). Selections from large number of ecotypes collected by B. R. Christie were the foundation of newly developed experimental synthetics at the Crops and Livestock Research Centre of AAFC in Charlottetown, P.E.I., and are presently under evaluation in an official registration trial established in 1999. Winter hardiness, persistence, and establishment under no till or reduced till systems continue to be the focus of this breeding program in Canada.

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July 20 / 20 juillet 2000
10:30 to 12:00 a.m.

Session 2: Pasture Systems

Thème 2: Pâturages

Moderator / Modérateur: Fraser Stewart

OPTIMIZING PASTURE MANAGEMENT FOR COW-CALF PRODUCTION IN QUÉBEC: THE ROLES OF ROTATIONAL GRAZING AND STOCKING RATE IN THE CONTEXT OF SYSTEM EFFICIENCY

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ABSTRACT

A two-year experiment was conducted in southwestern Québec to evaluate the impact of management intensive grazing (MiG) on pasture productivity, cow-calf performance and economic output. The 40 ha pasture contained mixed tall-grass species that was divided into 18 grazing cells. Sixty one spring-calving Angus cows with calves were assigned to nine treatments arranged as a 3 x 3 factorial of rotational frequency (RF) and stocking rate (SR), at the following levels: high RF (avg. 2d grazing period), medium RF (avg. 6d grazing period), and zero rotation (continuous grazing); high SR (0.5 ha^{-1} per cow-calf pair), medium SR (0.7 ha^{-1} per cow-calf pair) and low SR (0.9 ha^{-1} per cow-calf pair). Forage mass availability (FMA) to a 3 cm residual height was determined, and pasture samples analyzed for nutritional quality. Hay was harvested from rotationally grazed paddocks when herbage supply was abundant and offered late in the season to cows in paddocks with limited FMA. Increasing the RF had no effect ($P < 0.05$) on FMA throughout the season. During the latter part of the grazing season (August and September), FMA decreased linearly ($P < 0.05$) as SR increased. During July, August, and September, there were quadratic responses ($P < 0.05$) in forage crude protein (CP) concentration and CP available as RF increased; the highest pasture quality observed with 6-d rotational grazing. Increasing SR from 0.9 to 0.5 ha^{-1} per cow -calf pair resulted in a linear reduction ($P < 0.01$) in forage CP available in September. Most of the cow weight gain over the entire grazing season occurred during the first grazing month (June), when FMA was highest. A change from continuous to rotational grazing resulted in a linear decrease ($P < 0.01$) in cow gain ha^{-1} in June, but increasing the SR caused a linear increase ($P < 0.01$) in cow weight gain. Calf weight gain ha^{-1} increased linearly ($P < 0.01$) in response to SR, but was unaffected ($P > 0.05$) by RF. A 6d RF system at high SR generated the greatest net revenue, because of hay harvested early in the grazing season. The study revealed relatively little benefit of MiG on animal performance, but substantial benefit of MiG on the efficiency of land use and on economic output.

INTRODUCTION

Management intensive grazing (MiG), which utilizes rotational stocking with short grazing periods, has been reported to enhance pasture productivity and increase the performance of ruminants raised on pasture (Gerrish and Morrow 1999). However, the level of adoption of MiG in eastern Canada remains low (Clark et al. 1993; Petit 1993). Some of the factors limiting widespread adoption of MiG may include a lack of conclusive data on the benefits of rotational stocking (hereafter referred to as rotational grazing), limited scientific information on MiG, as well as uncertainty about the economic merits of pasture management. For example, rotational grazing is generally thought to improve animal performance (Clark et al.1993; Fales et al. 1995; Gerrish and Morrow 1999), but several workers have reported little or no benefit of rotational compared to continuous grazing (Hull et al. 1967; Bransby 1991; Popp et al. 1997).

The benefits of rotational grazing are highly dependent upon stocking rate (Young and Newton 1972), and according to Wheeler (1962), successful grazing experiments require that at least three stocking rates be investigated. Despite such caution, many studies have been conducted with only one or two levels of stocking rate or rotational frequency (Southwood and Robards 1975; Allen et al. 1991; Popp et al. 1997), and without consideration for the interaction between rotational frequency and stocking rate (Connifee 1976; Morrow et al. 1990). An analysis of the beneficial effects of grazing management is further complicated by results of Marshall et al. (1998a), which revealed distinct effects of grazing month on pasture quality. Thus, by ignoring monthly effects during the grazing season (Popp et al. 1997), differences in grazing systems between early and late season may be masked.

The economics of pasture management was investigated by Morrow et al. (1990) who concluded that rotational grazing increased profitability of the system. However, that study suffered limitations because of confounding effects of stocking rate and rotational grazing frequency. It is useful, though, to consider pasture management as the economic management of a resource, and to evaluate pasture utilization by invoking the concept of system efficiency. This would include not only measures of animal performance but also land use, and costs of hay production and hay supplementation on pasture. Such an approach may lead to a better understanding of the benefits and limitations of MiG, and provide the knowledge upon which to base recommendations regarding grazing systems for beef cattle. The aim of this research was to determine the influence of RF and SR on pasture, animal, and economic performance, with a view to better managing pasture resources for cow-calf production in Québec.

MATERIALS AND METHODS

Site, Animals and Experimental Design

The research was conducted in the southwestern region of Québec. It was carried out during two successive grazing seasons (June to October, 1997; 120 d season, and May to October, 1998; 135 d season) on 40 ha of improved, untiled pasture that contained predominantly smooth bromegrass (*Bromus inermis* Leyss.), reed canarygrass *(Phalaris arundinacea* L.) and quackgrass (*Elytrigia repens* (L.) Nevski). The configuration of the land required that the pasture be partitioned into two sections (blocks) of 24 ha and 16 ha each. Each block was divided into nine grazing cells with high-tensile electric wire. During the experiment, total grazing-season rainfall was above average in 1997 (702 mm) and below average in 1998 (422 mm).

Sixty one spring-calving, pregnant cows (purebred, black and red Angus, four to five years old; initial weight 543 $\pm$ 59 kg) were selected for the experiment in each of the two years. The experiment was conducted as a randomized complete block design with two blocks and nine grazing management treatments arranged as a 3 x 3 factorial of RF and SR. Each factor was studied at the following levels: high RF (average of 2d grazing period, 1-3 d range), medium RF (average of 6d grazing period, 4-8 d range), and zero rotation (continuous grazing); high SR (0.5 ha per cow-calf pair), medium SR (0.7 ha per cow-calf pair) and low SR (0.9 ha per cow-calf pair) for the duration of the grazing season. Cow-calf pairs were randomly assigned to one of the nine grazing treatment combinations. The continuous grazing treatments comprised six grazing cells with no internal fencing. Each of the six medium RF cells was subdivided into six paddocks, and each of the six high RF cells was subdivided into 16 paddocks . The targeted stocking rates were achieved by adjusting the land area that constituted a grazing cell. Where this was not possible, due to physical constraints of the site, the number of cows within a paddock was varied.

Pasture and Feeding Management

In each of the two years, similar procedures were adopted for pasture and feeding management. Herbage in the continuously grazed pasture was mechanically clipped at the end of July to a target height of 15 cm to remove grass seed heads, and to stimulate vegetative growth while ensuring availability of pasture forage. When herbage supply in the rotationally grazed paddocks was excessive, hay was harvested as round bales, and offered to cows grazing any grazing cell where forage availability was low enough to reduce body condition score to 3.0 or less. All animals were offered, free-choice, a commercial mineral-vitamin supplement which was combined with salt in a 2:1 ratio. Water was freely available to all animals within paddocks.

Measurements

Pasture sampling was performed by randomly throwing a quadrat (0.5 m x 0.5 m) at six different locations within a paddock; plant material rooted within the quadrat was then hand-clipped to a 3 cm residual height and composited. Forage mass was determined from the weight of composited samples and the DM content of the herbage. Forage mass available (FMA) in rotationally grazed paddocks

was defined as the mean of pre- and post-grazing forage mass. On the first and fifteenth day of each month, pre-grazing samples were obtained in the next paddock to be grazed, and post-grazing samples were obtained immediately after cattle were rotated out of the paddocks. For the continuously grazed paddocks, where pre- and post-grazing samples were inappropriate, estimates of FMA were based on single pasture samples taken on the first and fifteenth day of each month. For all treatments, dried samples of forage were analyzed for crude protein (CP), acid detergent fibre (ADF) and neutral detergent fibre (NDF). Body weights of cows and calves were recorded at the beginning and end of the grazing season, and on the 15th and 30th day of each month.

Economic performance was measured using net revenue (NR). It was based on the following four variables, all of which were monetized: 1) cow weight change (revenue); 2) calf weight gain (revenue); 3) hay harvested (revenue); and 4) hay supplemented (cost). The cost of hay supplementation was based on the quantity of hay provided to the cows and the price of hay.

Statistical Analysis

To remove the influence of seasonality on forage production and quality, all data were analyzed by month. Data were analyzed as a randomized complete block design (Steel and Torrie 1960) with a factorial combination of RF and SR. Data for FMA, forage quality and NR were analyzed using the GLM procedure of SAS (1989); the effects of year and block were accounted for in the model. Animal performance data were analyzed based on a mixed model, using the Mixed Models procedure of Littell et al. (1996); the effect of animal was considered random; whereas RF, SR, and the interaction between RF and SR were considered fixed effects.

RESULTS

Forage Availability and Quality

As the grazing season progressed, FMA declined; averaged over all treatments, FMA was 2270, 2220, 1820, and 1490 kg ha^{-1} in June, July, August, and September, respectively. Forage CP available also declined between June (average 252 kg CP ha^{-1}) and September (average 189 kg CP ha^{-1}).

With the exception of June, there was no interaction ($P<0.05$) between RF and SR on FMA (Table 1) throughout the grazing season. Rotational grazing frequency had no further effect ($P<0.05$) on FMA. During the latter part of the season (August and September), FMA decreased linearly ($P < 0.05$) as SR increased. In September, the combination of continuous grazing and the high stocking rate caused FMA to decline to 1.2 t ha^{-1}. At the beginning of the grazing season (June), at the low stocking rate, a change from continuous grazing to 2-day rotational grazing increased both forage CP concentration and CP available (Table 2). However, at the high stocking rate a change from continuous to 2-day rotational grazing decreased ($P< 0.05$) both forage CP concentration and CP available. This caused a significant interaction ($P < 0.05$) between RF and SR on both forage CP concentration and forage CP available. During the months of July, August, and September, there

were quadratic responses ($P < 0.05$) in forage CP concentration and CP available as RF increased; the highest values for forage CP were observed with 6-d rotational grazing. By the end of the season (September) the continuously grazed pastures contained the lowest CP concentrations. Increasing SR from 0.9 to 0.5 ha per cow-calf pair resulted in a linear reduction ($P < 0.01$) in forage CP available in September; there were no effects ($P > 0.05$) of SR on forage CP during the earlier months of grazing.

Forage fiber concentrations were not affected ($P > 0.05$) by treatment in June and July (Table 3). However, in August and September there were linear decreases ($P < 0.01$) in ADF and NDF concentrations of pasture as RF increased. Increasing stocking rate caused a quadratic response ($P < 0.05$) in NDF concentration in August; the highest NDF concentrations were observed at the medium SR.

Animal Performance

Averaged over all treatments weight gain of cows on pasture declined from 50 kg mo^{-1} in June, to 13 , 10, and 10 kg mo^{-1} in July, August, and September, respectively. Corresponding values for calves were 51 kg mo^{-1} (1.70 kg d^{-1}), 33 kg mo^{-1} (1.07 kg d^{-1}), 37 kg mo^{-1} (1.18 kg d^{-1}), and 42 kg mo^{-1} (1.40 kg d^{-1}), respectively.

Treatment effects on animal gain ha^{-1} are presented in Table 4. With the exception of results reported for August, there were no interactions ($P > 0.05$) between RF and SR on cow weight gain ha^{-1}. Increasing the RF resulted in a linear decrease ($P < 0.01$) in cow gain ha^{-1} in June. However, during the same month, increasing the SR caused a linear increase ($P < 0.01$) in cow gain ha^{-1} . In July, however, increasing both RF and SR resulted in linear increases in cow gain ha^{-1} ($P < 0.01$). A change from continuous to rotational grazing caused a linear increase ($P < 0.01$) in cow gain ha^{-1} during September, but SR had no effect ($P > 0.05$) during this period. There were no interactions ($P > 0.05$) of RF and SR on calf gain ha^{-1} throughout the season (Table 4). During all four months of grazing, calf gain ha^{-1} increased linearly ($P < 0.01$) in response to SR, but was unaffected ($P > 0.05$) by RF.

Net Revenue

The net revenue derived from the various grazing systems are presented in Table 5. There was no interaction ($P > 0.05$) between RF and SR on NR during any month of the grazing season. Throughout the entire grazing season, there was a linear increase ($P < 0.01$) in NR with increasing SR. In both early and late phases of the grazing season, RF had a quadratic effect ($P < 0.05$) on NR; the highest values were observed with the 6-day rotation.

Overall cow weight gain in June was 79.5 kg ha^{-1} , and calf gain was 82.4 kg ha^{-1}. Income from this animal gain was valued at \$284.86 ha^{-1}. In July, gains were 21.8 and 53.7 kg ha^{-1}, respectively, for cows and calves, and were valued at \$156.81 ha^{-1} ; corresponding gains in August were 15.7 and 58.4 kg ha^{-1}, respectively, and were valued at \$162.80 ha^{-1}. Weight gains in September were 13.9

kg ha^{-1} for cows and 67.1 kg ha^{-1} for calves, and were valued at \$183.07 ha^{-1}. The amount of hay harvested in June was 2.0 t ha^{-1} (valued at \$192.34 ha^{-1}), and in July, the hay harvest was 0.2 t ha^{-1} (valued at \$21.16 ha^{-1}); during August and September, no hay was harvested. The amount of hay supplemented was 0.1 t ha^{-1} and 0.7 t ha^{-1} (-\$10.97 and -\$67.70 ha^{-1}) in August and September, respectively. No hay was supplemented in June and July, or in any of the LSR systems throughout the entire season.

Cow weight gain ha^{-1} was maximized under the system of HSR-continuous grazing; this system was 9% (\$14.24 ha^{-1}) better than the next best system (HSR- 6 d RF), and 65% (\$65.37 ha^{-1}) better than the worst system (LSR-continuous grazing). Calf gain ha^{-1} was maximized under the HSR-6-d RF system which was 5% (\$40.97 ha^{-1}) better than the next best system (HSR- continuous grazing), and 89% (\$425.10 ha^{-1}) better than the worst system (LSR-2d RF). Pasture quality was maximized under the HSR-6d rotation system, which was 24% (2.5 percentage units difference in CP) better than the worst system (LSR- continuous grazing). Maximum FMA was achieved with the system of LSR-continuous grazing, which yielded 87% (0.91 t ha^{-1}) more FMA than the worst system (HSR-2d RF). Gross revenue from hay harvested was maximized under the system of MSR-6d RF, and no hay supplementation was required with LSR systems, irrespective of frequency of rotation. When all response variables were considered collectively, the HSR -6d RF system generated the greatest net revenue, \$293.05 ha^{-1}; this was 32% greater than the next best system (MSR- 6d RF), and 101% (\$614.56 ha^{-1}) greater than the worst system (LSR-continuous grazing).

The optimum system of HSR-6d RF yielded 46% (\$386.44) more NR ha^{-1} than the HSR - continuous grazing system. Of this amount, \$236.88 was due to hay harvested from the 6-d- HSR system, and it represented over 60% of the difference in NR. In addition, the 6-d-HSR system required only \$70.53 in hay supplementation cost, while the HSR-continuous grazing system required \$193.35. The other two components of net revenue, weight gain from cows and weight gain from calves, contributed little to the difference in net revenue between the two systems; cow weight gain from the HSR 6d RF system contributed \$14.24 less to net revenue than did the HSR- continuous system, and calf weight gain contributed \$40.97 more.

DISCUSSION

Forage Availability and Quality

The decline in FMA throughout the grazing season reflects the normal growth distribution of tall-growing cool-season perennial grasses that dominated the pastures. A similar decline has been reported in previous grazing research with cool-season species in Illinois and Ontario (Bertelsen et al. 1993; Marshall et al., 1998b). The observation that forage availability was unaffected by rotational grazing frequency is in agreement with previous studies by Hart et al. (1988) and Popp et al. (1997). However, the findings contrast with other reports that rotational grazing results in greater forage availability than continuous grazing (Walton et al.1981; Hoveland et al.1997). Since variable amounts of hay supplementation were required late in the season, there may have been a masking

of differences in pasture productivity associated with the different RF during the late season. Cows under the 2d RF required 39% more hay supplementation late in the season than did those under continuous grazing, and cows under the 6d RF required minimal hay supplementation. Assuming the amount of hay supplemented was inversely related to pasture productivity, late season pasture productivity may have been greatest under 6d RF, intermediate under continuous grazing and least with the 2d RF system.

The beneficial effect of 6-d rotation on forage CP was best seen in September when a change from continuous grazing to 6d rotation increased CP concentration from 114 to 137 g kg DM^{-1}, and CP available from 172 to 225 kg ha^{-1}, a 33% increase. The late season (August and September) reduction in NDF and ADF concentrations with rotational compared to continuous grazing is consistent with previous reports that pasture quality could be improved with rotational grazing (Walker et al., 1989 ; Gerrish and Morrow 1999). A high degree of selective grazing may have occurred in the continuously grazed paddocks early in the season when forage mass was abundant. This would have resulted in patches of mature, ungrazed, low-quality forage later in the season. The high grazing pressure associated with the 2-d rotation may have resulted in some paddock-level overgrazing, leaving stemmy residual material post-grazing , and probably limiting plant regrowth. This would reduce pasture quality, and could explain the observation that the 6d rotation resulted in the best forage quality from July through September.

The negative impact of high SR on FMA and CP available late in the season was probably the result of late-season overgrazing. This would have reduced plant regrowth and forage availability during those months. The effects of SR on forage availability is consistent with previous reports (Southwood and Robards, 1975; Owensby et al., 1988; Popp et al., 1997).

Animal Performance

Over the grazing season, values for average daily weight gain of cows ranged from 0.47 to 0.81 kg d^{-1} across all management systems; corresponding values for calves ranged from 1.20 to 1.36 kg d^{-1}. These gains are higher than those reported by Marshall et al. (1998b) for medium-frame spring-calving beef cows and calves grazing grass-legume pastures for 154 d in southern Ontario. Differences in performance may be related to our greater values for forage mass available.

An important feature of this study design was that it allowed us to assess differential effects of grazing systems at different phases of the grazing season. The results reveal that over 60% of the cows' weight gain over the entire season occurred in June. Because of forage abundance during this early part of the season and the greater potential for selective grazing, the continuous grazing system resulted in cow performance that was superior to that obtained with rotational grazing; calf gains, however, were similar across all grazing systems. Although late-season gains in cows were superior with rotational grazing, less than 40% of the entire gain occurred late in the season. Therefore, management systems that would affect animal performance over the entire grazing season must have their greatest impact early in the season.

At the start of the grazing season, cow live weight gain ha^{-1} was greater under continuous than rotational grazing, and increasing SR under continuous grazing further improved cow gain per hectare. The opportunity for selective grazing during this period of rapid pasture growth probably explains the higher gain ha^{-1} of cows grazing continuously. In addition, a high SR was advantageous to cow gain ha^{-1} by reducing under-grazing and promoting vegetative, high quality growth. The reduction in cow gain ha^{-1} with the combination of a 2-d rotation and HSR in the month of June, can be explained by the reduction in pasture quality where there was lower herbage allowance, lower CP concentration, and thus lower CP available.

Season-long rotational grazing was beneficial to animal performance only at the end of the season. During this time, despite the provision of supplemental hay, the poor quality and relatively low availability of forage in the continuously grazed pastures limited cow performance. Marshall et al (1998b) suggested that forage intake could be restricted by limited availability of forage during the latter part of grazing periods late in the season. This could explain the poor cow performance with the combination of high SR and 2d rotation in August when FMA declined to 1 t ha^{-1}. The improved performance in September with the high SR and 2d rotation can be explained by the fact that animals on this treatment combination received the greatest level of hay supplementation.

Only during the last month of the grazing season was the performance of calves affected by rotational grazing. Detrimental effects on cow performance due to continuous grazing late in the season, or advantages in cow performance early season were not reflected in calf growth. Cows may have acted as effective "buffers" against potential nutritional insults to the calves. Popp et al. (1997) also reported no effect of continuous versus rotational grazing on weight gain of stocker cattle. However, the profound effect of SR on calf gain per hectare during all four periods of the grazing season is consistent with the observations of Popp et al. (1997), who concluded that stocking rate is the key factor optimizing performance of stocker cattle on pasture.

Profitability and System Analysis

Economic analysis of grazing systems is not new (Ford and Musser 1998; Hart et al. 1988; Moore 1997; Bransby 1989; Heitschmidt et al. 1990). The framework for comparing production systems involves considering either market prices alone (gross revenue) (Bransby 1989), market prices together with production costs (net margins) (Heitschmidt et al 1990; Ford and Musser 1998; Hart et al.1988), or simply costs of production (Moore 1997). This study utilizes net revenue per hectare, an economic measure that captures revenue generated from animal performance and hay production, and the cost of hay supplementation.

This study clearly indicates that the optimum grazing management system depends on the response variable(s) which the producer wishes to consider. Moreover, the sensitivity of each of the response variables to a change in grazing management can vary substantially. The managerial implication of these findings is that cow-calf producers should concentrate their resources on those system variables that are most important and most responsive to changes in pasture management. On a 40

ha farm, for example, the net revenue advantage from a 6-d rotation-HSR system, compared to a continuous grazing -HSR system, would be over $15,000. Assuming a 135-d grazing season, the herd would require 22.5 moves (every six days) in a 6d rotation system. Based on 1 h of management for every hour of labor, the 6-d system would need less than $700 in additional labor expense[1]. With regard to cost differences in infrastructure, Moore (1997) estimates a differential of $111 ha^{-1} per year ($4400 for a 40 ha farm) for rotational grazing. Taking into account the differences in expense for labor and infrastructure, there would still be a residual benefit to MiG of $10,000 relative to a comparable continuous grazing system. Yet, most cow-calf producers are not adopting MiG system. Ford and Musser (1998) concluded that management inertia and negative attitudes towards grazing cannot explain the lack of adoption of profitable (grazing) innovations. There are three possible reasons to explain this paradox in grazing practices: 1) production and financial risk, 2) return on investment, and 3) methods of assessing the efficiency and adequacy of resource management.

To analyze the effect of management on production risk, it is useful to analyze the variability in output from the system, in addition to the average output from the system. Heitschmidt et al. (1990) reported that net margin per hectare under a continuous-high SR cow-calf system ranged from $-3.11 to $20.83 (a difference of $23.94) over a six year period. For their 4-paddock rotational system with a high SR, the range in net margin was $8.77 to $21.74 ha^{-1}, a difference of only $12.97. Therefore, the continuous system was 85% more variable. The "downside" production risk, which approximates the "worst-case scenario", was considerably less with the rotational system, ($8.77 vs $-3.11) while the "upside" potential of both systems was comparable ($20.83 vs. $23.94). In our study, the 6-d-HSR system had a difference in net returns per hectare of $250.48 compared to a continuous-HSR of $377.09, 51 % more variable. The downside production risk, based on the 95% lower confidence limit, was also less for the rotational system ($166.67 ha^{-1} vs. $61.63 ha^{-1}). In terms of upside potential, the two systems were comparable ($417.16 ha^{-1} vs $438.72 ha^{-1}). If graziers , like most people in society, are risk averse, then based on downside production risk, producers would be better off adopting a MiG system. Our study, as well as that of Heitschmidt et al. (1990), demonstrates that by introducing MiG technology, a producer could reduce the overall variability in net return, and raise minimum net revenue by 170%, without sacrificing "upside" benefits. Therefore, based on the analysis of net returns from rotational compared to continuous grazing, and on risk reduction, there appears to be ample incentive for producers to adopt MiG technology.

It is common, though, to evaluate the relative merits of rotational and continuous grazing based on animal gain (Popp et al. 1997). If one focuses solely on revenue from cow-calf weight gain, the MiG system only outperformed the continuous grazing system by 2.6 % ($26.73 ha^{-1}); for the 40 ha farm that would be $1069.20 for the grazing season. When compared with the $4400.00 as a cost for implementing the MiG system, the argument for adopting MiG is not compelling. If, however, we broaden the scope of the analysis, invoke the concept of systems management, and take into account hay harvested, hay supplemented, and land use, the benefits of MiG do emerge. The 6d RF system

[1]22.5 moves*1hour/move*($20/management hour + $10/physical labor hour)

generated \$236.88 ha^{-1} more revenue than the continuous system, and required \$122.82 ha^{-1} less hay supplementation. While we chose in this study to use surplus resources to produce hay, others may choose to use those surplus resources for alternative production, for example, stocker cattle. Thus, the real benefit of MiG for cow-calf producers may not be its impact on animal performance, but in the efficient use of the land resource.

CONCLUSION

This study reveals that the main determinant of calf gain ha^{-1} was stocking rate, not rotational frequency, and that cows appear to be effective buffers for their calves. In addition, the study shows that 60 % of cow weight gain occurs in the first month (June) of the season. Because of high forage abundance during this time, cows in continuously grazed paddocks had greater opportunity for herbage selection; this resulted in superior performance of cows under continuous compared to rotational grazing systems. Increasing the stocking rate early in season from 0.9 to 0.5 ha per cow-calf pair further improved cow weight gain ha^{-1}. Season-long rotational grazing was beneficial to animal performance only at the end of the season when forage availability was low, and rotational grazing improved pasture quality. However, because a relatively small proportion of total animal gains (less than 25%) occurred late in the season, net returns to management due to rotational grazing were relatively small. A system of 6d rotation and high stocking rate maximized net revenue from the management of resources, and this was due mainly to income from hay harvested in rotationally grazed paddocks. It is essential to adopt a systems approach to pasture management so that resource usage can be optimized, and the benefits MiG revealed.

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Table 1. Least square means for monthly forage mass available (FMA) during two grazing seasons under different rotational frequencies (RF) and stocking rates (SR).

	Continuous			6 d Rotation			2 d Rotation			Significance of Effects				
										RF		SR		RFxSR
	LSR	MSR	HSR	LSR	MSR	HSR	LSR	MSR	HSR	L	Q	L	Q	
							June							
FMA (tonnes DM ha^{-1})	2.36	2.37	2.33	2.46	2.31	2.50	2.58	1.99	1.55	NS	NS	NS	NS	*
SE	0.218	0.218	0.218	0.218	0.218	0.218	0.318	0.180	0.218					
							July							
FMA (tonnes DM ha^{-1})	2.27	2.17	2.04	2.62	2.55	2.09	2.16	2.15	1.89	NS	NS	NS	NS	NS
SE	0.289	0.289	0.289	0.289	0.289	0.289	0.421	0.238	0.289					
							August							
FMA (tonnes DM ha^{-1})	2.37	1.73	1.69	2.07	2.26	1.71	1.66	1.88	1.05	NS	NS	*	NS	NS
SE	0.254	0.254	0.254	0.254	0.254	0.254	0.370	0.210	0.254					
							September							
FMA (tonnes DM ha^{-1})	1.94	1.57	1.20	1.75	1.58	1.36	1.81	1.39	0.81	NS	NS	**	NS	NS
SE	0.223	0.223	0.223	0.223	0.223	0.223	0.324	0.184	0.223					

6 d Rotation = 4-8 d grazing periods; 2 d Rotation = 1-3 d grazing periods
LSR, MSR and HSR = low, medium and high stocking rates, respectively
SE = standard error; L = linear; Q = quadratic
NS= not significant; * = significant at $p<0.05$; ** = significant at $p<0.01$

Table 2. Least square means for monthly forage crude protein (CP) concentration and crude protein available (CPA) from pasture during two grazing seasons under different rotational frequencies (RF) and stocking rates (SR).

	Continuous			6 d rotation			2 d rotation			Significance of Effects				
										RF		SR		RFxSR
	LSR	MSR	HSR	LSR	MSR	HSR	LSR	MSR	HSR	L	Q	L	Q	
							June							
CP (g kg DM^{-1})	114	117	126	112	115	119	123	115	110	NS	NS	NS	NS	*
SE	4.4	4.4	4.4	4.4	4.4	4.4	6.5	3.7	4.4					
CPA (kg ha^{-1})	259	258	275	266	254	286	295	217	163	NS	NS	NS	NS	*
SE	28.8	28.8	28.8	28.8	28.8	28.8	41.9	23.7	28.8					
							July							
CP (g kg DM^{-1})	98	96	109	112	112	130	115	108	105	NS	*	NS	NS	NS
SE	7.6	7.6	7.6	7.6	7.6	7.6	11.0	6.2		7.6				
CPA (kg ha^{-1})	216	200	218	265	274	266	218	240	182	NS	*	NS	NS	NS
SE	30.6	30.6	30.6	30.6	30.6	30.6	44.6	25.2	30.6					
							August							
CP (g kg DM^{-1})	101	109	112	118	124	132	118	114	123	*	*	NS	NS	NS
SE	6.0	6.0	6.0	6.0	6.0	6.0	8.8	5.0	6.0					
CPA (kg ha^{-1})	223	182	188	247	284	235	204	211	141	NS	**	NS	NS	NS
SE	29.3	29.3	29.3	29.3	29.3	29.3	42.7	24.2	29.3					
							September							
CP (g kg DM^{-1})	108	108	125	141	129	142	128	128	129	NS	*	NS	NS	NS
SE	8.8	8.8	8.8	8.8	8.8	8.8	12.8	7.2	8.8					
CPA (kg ha^{-1})	203	164	149	249	225	199	223	181	104	NS	*	**	NS	NS
SE	27.7	27.7	27.7	27.7	27.7	27.7	40.3	22.8	27.7					

6 d Rotation = 4-8 d grazing periods; 2 d Rotation = 1-3 d grazing periods
LSR, MSR and HSR = low, medium and high stocking rates, respectively
SE = standard error; L = linear; Q = quadratic
NS = not significant; * = significant at $p<0.05$; ** = significant at $p<0.01$

Table 3. Least square means for monthly acid detergent fiber (ADF) and neutral detergent fiber (NDF) concentrations of pasture during two grazing seasons under different rotational frequencies (RF) and stocking rates (SR).

	Continuous			6 d Rotation			2 d Rotation			Significance of Effects				
										RF		SR		RFxSR
	LSR	MSR	HSR	LSR	MSR	HSR	LSR	MSR	HSR	L	Q	L	Q	
							June							
ADF (g kg DM^{-1})	301	315	299	310	310	311	309	312	308	NS	NS	NS	NS	NS
SE	7.3	7.3	7.3	7.3	7.3	7.3	10.6	6.0	7.3					
NDF (g kg DM^{-1})	543	563	512	555	552	544	537	557	552	NS	NS	NS	NS	NS
SE	14.5	14.5	14.5	14.5	14.5	14.5	21.1	11.9	14.5					
							July							
ADF (g kg DM^{-1})	350	356	341	340	349	349	334	349	345	NS	NS	NS	NS	NS
SE	6.1	6.1	6.1	6.1	6.1	6.1	8.8	5.0	6.1					
NDF (g kg DM^{-1})	597	616	588	569	590	578	580	587	588	NS	NS	NS	NS	NS
SE	17.2	17.2	17.2	17.2	17.2	17.2	25.1	14.2	17.2					
							August							
ADF (g kg DM^{-1})	356	359	360	351	354	346	334	354	340	*	NS	NS	NS	NS
SE	8.2	8.2	8.2	8.2	8.2	8.2	12.0	6.8	8.2					
NDF (g kg DM^{-1})	615	626	605	581	593	577	565	603	576	*	NS	NS	*	NS
SE	14.2	14.2	14.2	14.2	14.2	14.2	21.7	11.7	14.2					
							September							
ADF (g kg DM^{-1})	365	365	352	323	314	328	318	345	303	*	NS	NS	NS	NS
SE	17.7	17.7	17.7	17.7	17.7	17.7	25.7	14.6	17.7					
NDF (g kg DM^{-1})	624	630	582	529	533	551	530	573	518	**	NS	NS	NS	NS
SE	26.4	26.4	26.4	26.4	26.4	26.4	38.4	21.7	26.4					

6 d Rotation = 4-8 d grazing periods; 2 d Rotation = 1-3 d grazing periods
LSR, MSR and HSR = low, medium and high stocking rates, respectively
SE = standard error; L = linear; Q = quadratic
NS= not significant; * = significant at $p<0.05$; ** = significant at $p<0.01$

Table 4. Least square means for monthly animal gain per hectare (LWG ha^{-1}) for cow-calf pairs during two grazing seasons under different rotational frequencies (RF) and stocking rates (SR).

	Continuous			6 d Rotation			2 d Rotation			Significance of Effects				
										RF		SR		RFxSR
	LSR	MSR	HSR	LSR	MSR	HSR	LSR	MSR	HSR	L	Q	L	Q	
June														
Cow LWG (kg ha^{-1})	68.0	92.9	124.1	58.3	83.7	92.1	63.2	67.4	65.4	**	NS	**	NS	NS
SE	12.62	12.62	12.62	12.62	12.62	13.61	17.26	11.13	12.62					
Calf LWG (kg ha^{-1})	67.0	80.1	109.3	66.0	64.8	110.4	60.1	81.3	103.1	NS	NS	**	*	NS
SE	5.82	6.89	5.27	5.56	7.03	5.46	11.05	6.13	5.56					
July														
Cow LWG (kg ha^{-1})	8.2	9.4	15.0	25.2	14.7	37.8	11.8	24.4	49.6	**	NS	**	NS	NS
SE	7.80	7.80	7.80	7.80	7.80	8.41	10.67	6.88	7.80					
Calf LWG (kg ha^{-1})	41.2	51.3	73.4	36.5	54.9	72.3	35.4	53.7	64.8	NS	NS	**	NS	NS
SE	3.84	4.00	3.46	3.34	4.00	3.62	5.07	3.34	3.34					
August														
Cow LWG (kg ha^{-1})	16.4	18.2	39.9	6.0	8.9	15.5	28.4	19.4	-11.8	NS	NS	NS	NS	**
SE	8.70	8.70	8.70	8.70	8.70	9.39	11.90	7.67	8.70					
Calf LWG (kg ha^{-1})	42.2	59.2	71.5	44.0	57.3	82.6	43.0	57.0	68.6	NS	NS	**	NS	NS
SE	3.48	4.05	3.33	3.21	3.21	3.63	4.71	3.22	3.35					
September														
Cow LWG (kg ha^{-1})	12.4	0.3	-6.0	24.6	23.1	12.8	16.2	17.5	24.0	**	NS	NS	NS	NS
SE	6.80	6.80	7.06	6.80	6.80	7.34	9.31	6.00	6.80					
Calf LWG (kg ha^{-1})	49.4	60.3	86.3	48.6	71.0	91.4	50.1	62.3	84.1	NS	*	**	NS	NS
SE	3.01	3.33	2.88	2.78	2.78	3.00	4.06	2.53	2.78					

6 d Rotation = 4-8 d grazing periods; 2 d Rotation = 1-3 d grazing periods
LSR, MSR and HSR = low, medium and high stocking rates, respectively
SE = standard error; L = linear; Q = quadratic
NS= not significant; * = significant at $p<0.05$; ** = significant at $p<0.01$

Table 5. Least square means for system net revenue per month during two seasons of grazing management with different rotational frequencies (RF) and stocking rates (SR).

	Continuous			6 d Rotation			2 d Rotation			Significance of Effects				
										RF		SR		RFxSR
	LSR	MSR	HSR	LSR	MSR	HSR	LSR	MSR	HSR	L	Q	L	Q	
	June													
Revenue ($ ha^{-1})	231	285	440	332	340	493	306	288	357	NS	*	**	NS	*
SE	33.81	33.81	33.81	39.49	39.49	33.81	49.47	34.98	33.81					
	July													
Revenue ($ ha^{-1})	115	139	196	119	159	230	104	176	208	NS	NS	**	NS	NS
SE	21.48	21.48	21.48	21.48	21.48	21.48	31.28	17.72	21.48					
	August													
Revenue ($ ha^{-1})	123	160	206	116	158	230	133	164	154	NS	NS	**	NS	NS
SE	19.82	23.13	19.82	19.82	19.82	19.82	28.89	16.35	19.82					
	September													
Revenue ($ ha^{-1})	136	132	159	149	193	214	137	160	167	NS	**	*	NS	NS
SE	17.17	20.03	17.17	17.17	17.17	17.17	25.02	14.16	17.17					

6 d Rotation = 4-8 d grazing periods; 2 d Rotation = 1-3 d grazing periods
LSR, MSR and HSR = low, medium and high stocking rates, respectively
SE = standard error; L = linear; Q = quadratic
NS= not significant; * = significant at $p<0.05$; ** = significant at $p<0.01$

EXTENDING THE GRAZING SEASON USING PERMANENT PASTURES FOR BEEF COWS IN ONTARIO

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ABSTRACT

One small plot trial, over two years, and five trials using beef cows, have been completed with the objective of investigating fall stockpiled permanent pasture to extend the grazing season. The plot trials, conducted at the Elora Research Station, studied the influence of stockpiling date, application of nitrogen and harvest date on yield and quality of herbage organic matter. These studies were completed on a mixed grass sward, in which some tall fescue was present. The three stockpiling dates compared were mid-July, early August and mid-August, with harvest taken between mid- and late November. The three levels of N application were 0, 40 and 80 kg/ha. The early and middle dates of stockpiling increased yields of herbage organic matter by 27.7 and 9.3 % over the yield achieved by not stockpiling until mid-August (mean yield: 3346 kg/ha). Contrary to expectations, forage quality was not improved by stockpiling at a later date, which coincided with more immature forage. As expected, N applications of 40 and 80 kg/ha increased yields of organic matter by 17.3 and 30.5% over no N (mean yield: 3242 kg/ha). Crude protein content of herbage was improved with the application of N and there was a tendency for other parameters of forage quality to be improved also. In each year, forage quality declined in association with delayed harvest in the fall, although the degree of decline in quality differed greatly in each of the two years.

In the first animal trial using roughland pasture at the Elora Research Station, four groups of either non-lactating or lactating cows, with calves at side, were grazed in four fields of stockpiled pastures from mid-October to late December. Management of the pastures was by strip grazing using an electric fence, which was moved daily in a direction away from the water source and shelter to the opposite end of each field. Regardless of breed type or lactation, different groups of cows lost between 25 and 60 kg of bodyweight and up to 3.5 mm of backfat (as measured by real time ultrasound) over the 12 th rib, between October and December. These cows were in mid-gestation, so weight loss was not serious and may have been due to a relatively high stocking rate, where 1 ha of pasture provided approximately 250 cow grazing days in each field. Calves that were not weaned from the cows until the fall grazing was over did gain as well as calves that were weaned in September and fed a moderate energy creep feed indoors. In this trial, there was moderate snowfall before the fall grazing was complete and cows grazed through the snow effectively.

In a second short term trial using non-lactating cows fed indoors, dilution of 35% dry matter silage with snow, at 25 or 50% of the diet (w/w, as fed basis), did not significantly reduce dry matter intake. From these results as well as the observations made with animals eating stockpiled pastures covered with snow, we concluded that presence of snow in stockpiled pastures should not be a major factor that could affect the health of beef cows in this management system.

Over each of the last three years, trials were performed to evaluate the behaviour and performance of non-lactating pregnant heifers and cows on stockpiled permanent pasture at the New Liskeard Agricultural Research Station and how their performance may be affected by climate. The pastures were established in 1992 and consisted primarily of orchardgrass, timothy and quackgrass with white clover and trefoil also. Groups of cows were fed in each of four fields and two groups were fed indoors. In two of the fields, more legume was in the stands than in the other two fields. The fields used in these studies were relatively exposed, so a 'L shaped commercial windfence, with 30% porosity, was situated to provide shelter from prevailing wind. Strip grazing management, similar to the procedure used earlier at Elora, was used here. In years 2 and 3, daily fence movement was compared in two fields with twice weekly fence movement in the other two fields. Mean maximum ambient temperatures each year ranged between highs of $+20^0$C at the beginning of each period to -5^0C at the end, with corresponding ranges in minimum temperatures from as high as $+10^0$C to as low as -25^0C. Low precipitation but normal snowfall characterized the first year, with normal precipitation and no snowfall in the second year and normal precipitation with below normal snowfall in the third.

Yields of herbage dry matter at the start of grazing were 3.85, 2.68 and 4.07 tonnes/ha overall fields in years 1, 2 and 3, respectively. Corresponding carrying capacities over grazing periods of 71, 76 and 70 days were 125.4, 132.7 and 201.5 animal grazing days/ha. Lower yield of herbage in year 2, compared to the other two years, was attributed to unusually dry conditions during mid- to late summer of 1998. To allow similar carrying capacity to year 1, pastures were grazed more severely in year 2 without a major impact on animal performance. Cows gained weight and condition each year of the study and bodyweight and condition changes of cattle on pasture were similar to those of cows eating hay indoors and were not affected by field (legume content) or grazing management (fence movement daily vs. twice weekly). From serial measurements of animal weight and condition, it was apparent that cows could loose weight and condition in the late season, when colder weather and/or snow was more prevalent than earlier in the season. Analyses of forage quality are not yet complete, but preliminary results confirm decline in quality over the grazing season, which had been observed in the earlier plot trials conducted at Elora.

Preliminary results suggest that fall grazing of pastures may compromise growth of herbage in these pastures early the following season but longer term impacts don't appear as serious. To avoid negative longterm impacts of grazing these pastures, it is important to avoid pugging and compaction as a result of excessive stocking rates and/or wet conditions.

The interest in this research among cow-calf producers in Ontario has been quite intense, although adoption of the technology may be fairly limited.

RE-EVALUATION OF NATIVE PLANT SPECIES FOR SEEDING ON THE SEMIARID PRAIRIE OF WESTERN CANADA.

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ABSTRACT

There is a growing interest in the re-vegetation of disturbed prairie sites, including annual crop lands, with native species. Previous research from the Brown Chernozem soil zone, or semiarid prairie region, of western Canada found that introduced forage species produced more spring forage with better nutritive value than native species and that native species exhibited little agronomic merit. However, current studies and reports from elsewhere indicate that native species will be useful for extending forage productivity and the grazing season into the late summer, fall and winter. They also contribute to biodiversity, improved soil organic matter, and wildlife habitat in this region. They may contribute to increased soil carbon sequestration, increased stability in the event of climate change, and possibly to nutritional or pharmaceutical products. Future opportunities in native plant research and development are identified.

INTRODUCTION

Over the last decade, there has been a renewed and growing interest in native plant species and this interest has contributed to the formation of the Prairie Conservation Action Plan, the popular Native Plant Summit conferences, and the formation of new groups such as the Native Plants Society of Saskatchewan. This revival can be attributed to several regional trends and changes to the agriculture industry in the Brown Chernozem soil zone of southwestern Saskatchewan and southeastern Alberta.

Private and public organizations that manage native prairie landscapes have recognized the importance of re-vegetation on disturbed sites with native rather than introduced plant species. For example, pipeline right-of-ways and well-sites in the petroleum industry are now seeded with native species. Ducks Unlimited Canada has promoted the value of seeded native species for ground-nesting waterfowl habitat on sites adjacent to permanent water bodies.

Cattle producers have increased appreciation for native rangelands due to training in intensive grazing management based on ecological principles. Native rangelands in the Northern Great Plains

can support good summer weight gains on yearling steers (Karn and Lorenz 1983) and were similar to some introduced grasses (Smoliak and Slen 1974). As changes to transportation and input costs make grain production uneconomical on some soils, the interest in re-seeding native species for summer, fall and winter grazing has grown. Fall and winter grazing of beef cattle, particularly pregnant non-lactating beef cows, is one strategy to reduce the cost of beef production in this region.

The Conservation Reserve Program (CRP) in the United States promotes the re-vegetation of land that is marginal for annual crop production and has a strong emphasis on native species. The CRP has increased soil organic carbon on fragile soils in the Northern Great Plains (Gephart et al. 1994). A Conservation Cover Program has been proposed for Canada to return land to perennial cover and also has an emphasis on native species. Soil associated with re-established native species could be a sink to sequester carbon removed from the atmosphere via photosynthesis and stored as soil organic matter carbon (Christian and Wilson 1999; Janzen et al. 2000). This process could contribute to Canada's international commitment to reduce greenhouse gas emissions. Even in urban settings, there has been a growing demand for native plants for low-input xeriscaping.

Invasion of native rangelands by weeds and introduced forages has been highlighted as a problem of previous revegetation efforts. The introduction of the Species at Risk Act in the federal parliament, an act to promote the preservation of endangered species in Canada, has heightened awareness of the need for the preservation of native mixed prairie rangelands and wild habitats.

Native plants were used by the first peoples of Canada for medicinal purposes and there is renewed interest in plants as a source of pharmaceutical and nutritional products. A recent market assessment of native plants in Saskatchewan commissioned by the Native Plants Society of Saskatchewan and the Northwest Saskatchewan Grasslands Association (Solutions 2000+, 1997) forecasts a 15% yearly increase in market size for native plants with specific reference to medicinal plants.

The purpose of this report is to review previous and current research on native plant species of the semiarid prairie region in light of some of these trends. A second objective is to identify opportunities for further research and development of native plants for seeding on the prairie landscape.

Adaptation

Establishment of plant species from seed is a key process in re-vegetation of disturbed sites, development of new pastures for livestock grazing, or range improvement. Some research results suggested that native grasses were difficult to establish (Kilcher and Looman 1983). The seed of native species that failed to establish in that study were obtained from Kansas, Nebraska and Colorado but these locations were too far south to provide adapted ecotypes for western Canada (Tober and Chamrad 1992). Recent results indicate that cultivars of native grasses developed for Montana and North Dakota can be successfully established from seed in western Canada (Table 1) although cool-season grasses (C_3) established better stands than warm-season (C_4) grasses.

Table 1. Establishment of native grasses in two studies.

Common name	Latin name	Kilcher and Looman 1983	Jefferson et al. [manuscript in preparation]
		----------%----------	
Northern wheatgrass	*Elymus lanceolatus* (Scribn. & J.G. Sm.)	90	94
Western wheatgrass	*Pascopyrum smithii* (Rydb.) A. Love	80	94
Green needlegrass	*Nasella viridula* (Trin.) Barkworth	90	90
Big bluestem	*Andropogon gerardii* Vitman.	5	78
Little bluestem	*Schizachyrium scoparium* (Michx.) Nash	3	44
Prairie sandreed	*Calamovilfa longifolia* (Hook.) Scribn.	5	51
Indiangrass	*Sorghastrum nutans* (L.) Nash	11	32
$LSD_{0.05}$		NR[1]	7

[1] NR- Not reported.

Lawrence and Ratzlaff (1989) concluded that native species were not persistent when seeded at Swift Current, Saskatchewan. The native grasses that they tested included five slender wheatgrass (*Elymus trachycaulus* (Link) Gould ex Shinners) entries, four awned wheatgrass (*Agropyron subsecundum* (Link) Hitchc.) entries, two northern wheatgrass entries and one streambank wheatgrass (*Elymus lanceolatus* (Scribn. & J.G. Sm.) Gould ssp.*lanceolatus*). These species were compared to three introduced forages, crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.), intermediate wheatgrass (*Elytrigia intermedia* (Host) Nevski) and meadow bromegrass (*Bromus riparius* Rehmann). These authors concluded that the slender wheatgrass lacked winterhardiness or persistence as it died in the fifth year after establishment. This conclusion was then extrapolated to all native species relative to introduced grasses for the semiarid region of western Canada. However, the authors failed to note that slender wheatgrass and awned wheatgrass are known to be short-lived perennials and die out

in 3 to 5 years. Thus, their primary conclusion and its extrapolation to all native species were both erroneous and supported the authors' *a priori* hypothesis. Northern wheatgrass exhibited no stand loss in this trial but this result was obscured by the results from slender and awned wheatgrasses.

Current demonstration and continuing research projects (Waller et al. 1994; Schellenberg and Jefferson 1998; Banerjee and Schellenberg 2000) have succeeded in establishing various native grass, shrub and forb ecotypes in the Southern portions of Saskatchewan, although more research is needed to establish proper seeding and establishment procedures, advantages of monocultures versus mixtures, determining the role grazing animals play in perpetuating the local plant population, developing proper grazing management strategies and evaluating the productivity and environmental condition of the stands in the short and long term.

Forage production

Direct comparisons of native and introduced species at Swift Current have generally examined biomass productivity as the main criteria and concluded that introduced species produce more forage biomass than native species (Lawrence and Troelsen 1964; Lawrence 1978; Kilcher and Looman 1983; Lawrence and Ratzlaff 1989). However, 90% of the variation in forage production among native and introduced species in the report of Kilcher and Looman (1983) could be explained by variation in stand establishment. Other studies (Coupland 1974; Dubbs et al. 1974; Hanson et al. 1976) have shown native grasses to compare favorably with introduced species. Knowles (1987) reported that western wheatgrass excelled in pasture yields and deserves attention for seeding long-term pastures. He also noted that introduced grasses were less productive during the summer period than native species which continued to grow. In another report, sites seeded with an introduced species mixture produced more forage than sites seeded with native species in Manitoba and Alberta while there was no difference between the two types in Saskatchewan (Jefferson et al. 1999).

The biomass productivity advantage of the introduced species over native species was dependent on soil fertility (Johnston et al. 1968). Introduced species yielded more forage than native range only when fertilizer had been applied and introduced species that were not fertilized yielded less than unfertilized native range. Knowles (1987) also observed greater response to fertilization by introduced species compared to natives. Most ranchers in the semiarid prairie region find fertilizer application to forages to be economically risky due to variation in rainfall and productivity response to fertilizer application. Forage biomass productivity comparisons may have been biased by seeding the species on the research centre where available soil nutrients and weed control are significantly above average. These studies were also relatively short term in nature (1 to 3 years) while the yield of introduced grasses tends to peak 2 to 3 years after seeding and declines thereafter (Knowles 1987).

Thus, the biomass productivity advantage of introduced species is likely less on typical semiarid prairie pastures than that reported from research centre trials. One exception may be crested wheatgrass as it has been reported to maintain its productivity advantage over native rangeland for

very long periods of time without fertilization (Smoliak et al. 1967). Crested wheatgrass on community pastures was twice to ten times more productive than adjacent native range (Smoliak et al. 1967; Looman and Heinrichs 1973).

Biomass productivity comparisons of native and introduced species are difficult to interpret due to the interaction of soil type, fertility, testing period, management (for example - clipping frequency), climate and possibly other edaphic factors. We conclude that the advantage in forage productivity of introduced forage species under intensive agronomic management is the primary reason for continued use of these species for hay and spring pasture production in the semiarid prairie region. However, native plant species have advantages in low input sustainable pastures for summer, fall and winter grazing.

Grazing and Forage quality

It would be difficult to envision a selection of introduced grasses which could provide the flexibility to withstand extreme environmental conditions and grazing pressures offered by grass species native to the mixed prairie. Kamstra (1973) reported that native grasses have specific seasonal growth characteristics that can vary its nutritional quality as maturation proceeds. Therefore, direct comparison of quality components between cultivated and range grasses at equivalent maturity stages cannot be made accurately since the usual definitions do not consistently apply to range grasses. For example, many range grasses produce seed only during favorable years. In addition, Knowles (1987) and Coupland (1974) reported that western wheatgrass and northern wheatgrass showed high senescence compared with cultivated grasses.

Pastures containing three native grasses, northern wheatgrass, western wheatgrass and green needlegrass, were established in 1993 and 1994 at Swift Current for the grazing of beef cattle in summer, fall and early winter. Calf gains on pasture in fall and early winter were nearly as good as those observed in feedlots (Jefferson et al. 1997). Estimates of forage production and grazing capacity (grazing days per ha) on the native grasses were similar to those reported for introduced grasses. A monoculture of western wheatgrass exhibited better forage quality for winter grazing than a mixture of northern wheatgrass, western wheatgrass and green needlegrass. In another study, the digestibility of western wheatgrass harvested in September (505 g kg^{-1}) was higher than that of northern wheatgrass (444 g kg^{-1}) (Jefferson, unpublished data). Western wheatgrass maintained good herbage quality throughout the grazing season in North Dakota (Frank and Bauer 1991; Hofmann et al. 1993) but can have low forage quality when harvested at a late phenological stage (Smoliak and Bezeau 1967). However, our results agree with Knowles (1987) that western wheatgrass has better forage quality than northern wheatgrass and has good potential for fall grazing.

Shrub species, such as winterfat (*Krascheninnkovia lanata* syn. *Ceratoides lanata, Eurotia lanata*), have superior forage quality for late fall and winter grazing (Smoliak and Bezeau 1967). Winterfat can be successfully re-established from seedings (Romo et al. 1997; Schellenberg unpublished data) and could contribute to significant improvements in cattle gains on fall and winter pastures.

The quantity and quality of forage produced on rangelands are highly cyclical, within and between years. Precipitation, plant species, and the proportion of cool and warm season species greatly affects overall forage quality of rangeland at any point in time. In general, diets from dormant range contain 4 to 7% crude protein (CP) with higher concentrations occurring from late summer to early fall and lower concentrations occurring from late fall through winter. Plants in a vegetative state generally contain over 10% CP (Abouguendia 1998).

Organic matter digestibility and CP of most native grasses from May till Sept. (Abouguendia 1998) are able to meet the lactation requirements of a beef cow or a growing yearling (0.45 kg gain d^{-1}) based on the guidelines developed by Holecheck and Herbel (1986). Phosphorus (P) is the most limiting mineral to range livestock production and adequate plant P concentrations for growth or lactation occurs only for a brief period early in the growing season, i.e., vegetative phase. Calcium (Ca) levels of native grasses are adequate for maintenance, growth and lactation throughout the year (Abouguendia 1998). Clearly, cattle grazing on only native grasses in late fall, winter and early spring will require protein and P supplementation. Phosphorus supplementation may also be needed during the growing season to satisfy the needs of lactating cows and growing animals (Abouguendia 1998). However, including forbs and shrubs in cattle diets improved cattle performance during periods when grasses were dormant and low in quality (Holechek et al. 1989). Several studies reviewed by Holechek et al. (1989) found that leaves from forbs and shrubs contain more protein, P, and cell solubles than do grasses at comparable stages of maturity. Schellenberg and Jefferson (1998) reported that two native woody shrubs, winterfat and Nuttall's saltbush (*Atriplex nuttallii*), found in southwest Saskatchewan and southeast Alberta retain their nutritive value well into the fall and early winter (CP about 11.5%). Although information is limited on associative effects between forages on intake, research has reported that browse species in the diet may increase digestibility of grasses and increase the overall digestibility of the total diet (Milchunas et al. 1978). During winter, shrubs with a higher CP content could improve the intake of grasses with crude protein levels below 7% by providing rumen microbes with a source of nitrogen (Cordova and Wallace 1975). Arthun et al. (1992) concluded that adding forbs or shrubs with low-quality grass forage had a similar effect on ruminal digesta kinetics and fermentation patterns as including alfalfa hay.

Research by Abouguendia (1998) revealed wide variations in nutrient contents and digestibility among native growth forms and among species within a growth form. Therefore, it is important to identify the main species and their proportions in each field in order to make efficient use of the available nutrient supply over the grazing season and across the landscape. The current native vegetation in southern Saskatchewan is dominated by C_3 species (Coupland and Rowe 1969), however, some C_4 grasses are found in the native grasslands (Tober and Chamrad 1992). Since these forage grasses grow at different rates and patterns throughout the growing season it is plausible that different grazing management could alter growth response and overall productivity (Waller et al. 1994). C_4 grasses can support increased grazing livestock production during the traditional summer slump of C_3 forages. Cattle performance improved when both C_3 and C_4 grasses were grazed (Ward 1988).

Selective foraging by herbivores (preferring some plants and avoiding others) affects the character and composition of rangelands and nutritional quality of the diet (Wallace et al. 1972). Some plant species have relatively low palatability or preference by grazing animals, yet were found to have a remarkably high nutrient content. Thus, proper grazing management may enable more complete utilization of such plants (Abouguendia 1998). Bai et al. (1998) reported that moderate stocking rates tended to favor greater plant species diversity. Therefore, increased diversity would improve the productivity of the pasture and the nutritional status of the grazing animal.

Crested wheatgrass was selectively grazed by beef steers over native grasses at vegetative and anthesis growth stages (Cruz and Ganskopp 1998). At a mature phenological growth stage, some native grass species were more preferred than crested wheatgrass while others were similar to it. This preference was observed in a pasture where crested wheatgrass was a large proportion of available forage and in a rangeland site where crested wheatgrass was a small proportion. These authors concluded that native grasses can provide summer and fall grazing while crested wheatgrass should be utilized in spring.

The diets of grazing cattle can also be improved by better grazing systems. Complementary grazing is a system currently promoted in the western parts of Canada and may be a more efficient use of pasture and can sustain higher stocking rates than continuous season-long grazing. In this system cattle are moved through a sequence of pastures with forages that mature in sequence over the season, thus allowing the cattle to access the forage when it has its best quality (Martin and Fredeen 1999). This type of system provides a method of integrating the use of native range plants with seeded pasture to delay grazing of the native range and to provide a means to improve the nutrient status of grazing cattle over a longer grazing season (Adams et al. 1993). Since native species possess a number of different attributes such as persistence, late season forage quality, salinity and drought tolerance, it is plausible to envision the role that native species may have in complementing existing native range and stands of cultivated forage species.

Seed production

Native grass species exhibit large annual and environmental variation in seed production (Jefferson et al. [manuscript in preparation]). Northern wheatgrass and western wheatgrass plants exhibit strong rhizomatous growth habit with reproductive tiller density declining over time as vegetative tillers eventually dominate the sward. Slender wheatgrass seed production has been commercialized and high yields are reported for this species (Lawrence and Ratzlaff 1989). While high commercial seed yield results in low seed costs for this species, it may also contribute to excessive proportions of slender wheatgrass in native species mixtures for revegetation projects. This species can dominate native stands for several years after establishment due to it's rapid establishment and competitive advantage over other grass species.

Most native species have undergone little if any selection for agronomic characteristics to improve germination, seed processing and handling, seedling establishment or to reduce seed dormancy

(Young and Young 1986). Baskin and Baskin (1998) noted that the seed of forbs and many native grasses studied to date were dormant at maturity. Most shrubs have varying forms of seed dormancy combined with varying lengths of viability once dispersed from the plant (Baskin and Baskin 1998). For example, *Tamarix pentandra* seed remains viable for only a few weeks. Many native seeds have structures which increase difficulty of handling. White prairie clover hulls are difficult to remove and inhibit germination. *Stipa* spp. have awns as well as barbs at the tip which result in lodging within seeding and cleaning equipment. Winterfat has hairy bracts which decreases flow of seed within a seeder but are required to supply calcium to the developing seedling. *Atriplex nutallii* seed is encapsulated within woody bracts which protect the seed but also decrease imbibition and make assessment of seed size difficult.

Current research efforts at Swift Current are focussed on development of varieties of native plants from collections of ecotypes made within the prairie provinces. These varieties were based on population development that endeavoured to capture the maximum genetic diversity from the original ecotypes. We need to confirm the genetic diversity of the resultant populations, evaluate their range of adaptation across the region, and develop seed production technologies to ensure their commercialization. Much of the information on seed production technology presented at Native Plant Summits appears to be anecdotal in nature. Further study is needed to test, modify and extend this information to other species, other producers or interested parties to permit more efficient and lower cost of seed production.

Soil fertility and carbon

Perennial forages are usually grown on low productivity soils, and ranchers seldom manage fertility for them as well as they do for their annual grain crops (Follett and Wilkinson 1995). Sustainable production systems are those that rely on minimal inputs of energy and chemicals to achieve long-term productivity and environmental compatibility (Poincelot 1987). Consequently, any sustainable production system must depend on efficient nutrient management, and, improved nutrient utilization requires greater understanding of the role of biological processes in the release of nutrients from soil organic matter.

Organic matter content is fundamental to maintenance of soil fertility because the mineralization of nutrients is critical to plant growth. The rate at which nutrients are released from soil organic matter is influenced by the chemical composition of the organic matter (including crop residues and root biomass), landscape position, and climate. For a successful sustainable forage production system we need to quantify the dynamics of soil nutrient mineralization as influenced by geographic and topographic position. In addition, litter (herbage residue after grazing) is essential in sustaining the prairie ecosystem without inputs of energy and as a sink for plant nutrients (Wilms et al. 1994). Thus, characterization of soil organic matter (including forage residues, root biomass) and nutrient mineralization rates in forage fields in the prairies will be an integral part of the sustainable forage production in the region.

Forage stand productivity generally declines with age but is only partially reversed by fertilization (Knowles 1987). Thus, a better understanding of the soil nutrient mineralization will help us manage long-term stands of seeded native species for sustainable stocking rates.

When soils are cultivated for crop production, particularly annual crops, the natural plant-soil system is modified (Gregorich et al. 1995) and soil organic matter levels decrease. This is due to the increased decay of existing soil organic matter as a result of tillage and alterations in temperature, moisture and aeration conditions as well as changes in the nature of crop residue (straw and root) additions (Swift et al. 1979). The planned conversion from arable agriculture to continuous grass production, either as pasture or as restored native prairie, will result in an increase in soil organic matter levels (Dormaar and Carefoot 1996), and thus enhancing soil carbon (C) sequestration. Efforts to meet national targets to decrease carbon emissions for Kyoto could be aided by planting perennial native plants on land that is marginal for annual crop production. The CRP land in the US has greater soil organic carbon than land that was in annual crops (Follett et al. 1999). Soil microbial biomass levels in the 0-60 cm depth were 28% higher in CRP soils and 81% higher in native rangeland soil compared to soils from cropland. Janzen et al. (2000) noted soil organic carbon in rangeland soil may exceed all above-ground portions of a temperate forest and this amount can be increased by returning previously-cultivated land back into grassland.

Bremer et al. (1994) found *Agropyron* spp. put down more total organic soil C and light fraction C than wheat (*Triticum aestivum* L.) or forage hay. Soil from a long-term stand of crested wheatgrass had less soil organic carbon after 23 years while nearby native range was unchanged (Smoliak and Dormaar 1985). Frank et al. (1999) noted native mixed prairie had greater potential as a carbon sink than a monoculture of western wheatgrass. This may have been due to increased root mass with a variety of species occupying different zones within the soil. Christian and Wilson (1999) suggested that since total C was less in soils under crested wheatgrass than under successional prairie, the planting of crested wheatgrass on millions of hectares of the Great Plains may have left 3.3 - 4.8 X 10^{14} g of C in the atmosphere that otherwise would have been stored as soil organic matter by native grass. Native species will be preferred to introduced forage species for soil carbon sequestration projects on the prairies.

The Canadian Government has committed itself to reduce its greenhouse gas emissions six per cent from 1990 levels by the year 2010. A reduction in net emissions can be achieved by either reducing emissions or enhancing sinks of C, such as accumulation or sequestration of C in soils (Izaurralde et al. 1997). Nevertheless, data is lacking to confirm the extent and rate of C sequestration under grassland after conversion from annual crop rotation to perennial native species. Increased soil organic matter is often associated with plants with large and finely branched root structures such as native grass species (Smoliak and Dormaar 1985; Gebhart et al. 1994). Pasture management systems could change the nature of soil C sequestration (Banerjee et al. 2000) by altering the method of deposition of organic residues and soil aeration. This results in a change in the amount of C or nitrogen being released or stored in the soil system. Thus, re-established grasslands could contribute towards decreased greenhouse gases by sequestering more C into the soil sink.

Biodiversity

Native prairie has higher biodiversity than traditional monoculture agricultural production. Conserving biodiversity in pastures provides many opportunities as well as challanges (Paoletti et al. 1992). Few biodiversity data are available to compare undisturbed ecosystems to agroecosystems (Paoletti et al. 1992). Native prairie is one of the more threatened ecosystems with major portions of the grasslands utilized for crop production. Ecosystem productivity increased as biodiversity increased in 146 plots located in Minnesota (Tilman et al. 1996). Tilman and Downing (1994) also found primary production was more resistant to drought with increased biodiversity. The nutritional value for grazing ruminants of rangeland with a greater diversity was higher later in the growing season (Smoliak and Bezeau 1967). While introduced species pastures have good nutritional value in spring and early summer, Cook (1972) demonstrated that the nutritive value of native grasses, forbs and shrubs can meet the nutritional needs of grazing livestock, particularly later in the growing season. The proportion of shrub species, including winterfat, in revegetation seed mixtures was higher for government projects in Nevada, USA, when biodiversity and habitat restoration were primary objectives compared to projects where watershed protection and soil erosion control were the primary objectives (Richards et al. 1998). These authors concluded that the cost of diverse seed mixtures of native species frequently restricts their use, even by agencies whose own policies promote the use of natives in preference to introduced species.

The decision to include native or introduced species in rangeland seeding is a multiple component process that includes philosophy, objectives, site potential and limitations, availability and cost of plant materials, weed invasion, desired community seral stage, and economic limitations (Jones and Johnson 1998). These authors document several known interspecific hybrids that have been reported to occur naturally on grasslands to support their position that genetic change and intra-specific diversity can occur naturally. While genetically diverse populations of native species would be ideal for re-vegetation, such ideals are often unavailable or too expensive for large scale projects. Knowledge of the species' genetic variation in relation to the ecological adaptation and their interactions with other ecosystem components is needed to make best decisions. While genetically diverse native cultivars, called ecovars™, are currently under development for large scale revegetation projects, it is uncertain that these varieties have maintained genetic diversity and broad adaptation after selection for seed yield.

Biodiversity on semiarid rangelands and pastures will be an important issue to Canadian society and merits additional research. The means to establish shrubs and forb species to increase biodiversity and carrying capacity needs additional research. The genetic diversity of native cultivars must be determined to confirm that diversity was maintained during selection for seed yield.

Climate change

Climate change will alter where agricultural production takes place in the USA (Antle 1997). World Resources Institute (1990) reported the mean May-August temperatures would rise 3.5°C, length of

the growing season would increase by 4 to 9 weeks with increased frequency of drought in July and August. As a result a shift in plant community species would occur to species that tolerate water stress and compete strongly for nutrients. Cutforth et al (1999) examined long term weather records of an area 15,000 km^2 of semiarid prairie southwest of Swift Current, Saskatchewan and found that winter and spring maximum and minimum temperatures have increased and that precipitation has decreased. Long-term climate change in southwestern Saskatchewan favoured C_3 species. Increasing C_3 native grass species production was found over the past centuries compared to C_4 species at Grasslands National Park located in the semiarid prairie region near Val Marie, Saskatchewan (Peat 1997). Work in Colorado (Alward et al. 1999) using long term vegetation data found a similar shift in production with warmer nights and lengthened growing season. Native species may provide useful genetic resources to respond to future climate change.

Bio-invasion

Bio-invasion can be defined as the replacement of native species by exotic species, generally introduced to the environment through human activity. Armstrong (1995) indicated that as many as 80% of the world's endangered species are threatened due to the competitive pressures of exotic species.

Bright (1998) provides the following example from Australia's attempt to identify superior forage species. Of 466 forage species introduced to Australia, only 21 have shown merit but 60 were found to be invasive. These 60 invasive species included 17 of the 21 forage species identified as having agronomic merit. Thus, only 4 of the 21 species with merit were deemed non-invasive.

The use of introduced forage grass species throughout North America for pastures and erosion control has led to the widespread distribution and dominance of these species (Haber 1996). White et al. (1993) have listed smooth bromegrass and yellow and white sweetclover as moderately invasive while alfalfa, crested wheat grass and Kentucky blue grass as minor invasive species of uplands.

The proportion of exotic flora in western Canada was estimated 16% (Haber 1996). In Saskatchewan, smooth bromegrass and crested wheatgrass were deemed invasive of native fescue grassland (Romo and Grilz 1990). Crested wheatgrass seedings were not invaded by native plant species until stands were more than 15 years old (Looman and Heinrichs 1973). Where native species were found in older crested wheatgrass stands, their contribution to above ground biomass did not exceed 10% of the total annual production. Thus, crested wheatgrass monoculture seedings appear to resist successional change even under heavy grazing utilization. Similar results were found in crested wheatgrass pastures of southern Alberta (Smoliak et al. 1967). The bio-invasive risk of introduced forage plant species has not been systematically evaluated for most, if not nearly all, introduced forage species of the semiarid prairie.

This is not to say all native species are benign. Hammermeister and Naeth (1999) noted three wheatgrasses, slender, northern and western, investigated in their research of native seed mixes were

invasive but northern wheatgrass was the most aggressive. They recommended that the proportion of native wheatgrass seed be reduced in mixtures. We also have observed rhizomatous spread of northern and western wheatgrasses into adjacent research plots after one to two years. Although natives can be invasive they are viewed as more desirable than introduced species by the environmental community. Increasingly legislation is being enacted which requires use of native species for re-vegetation in or adjacent to native rangeland and the provincial government of Alberta has taken the lead in this area.

Alternative uses

Native plants have the potential for multiple uses. *Echinacea angustifolia* is an example of a naturally occurring species in Saskatchewan which has large market presence for its nutritional and pharmaceutical value. The market for such species has grown and is expected to continue to expand for a number years (Solutions 2000+ 1997). Purple prairie clover, *Petalostemon purpureum*, Canadian milkvetch, *Astragalus canadensis*, and winterfat, species included in ecovar™ development program, have potential for nutritional or pharmaceutical products but information tends to be anecdotal (Johnston 1987; Kindscher 1992).

CONCLUSION

Native plant species will contribute to sustainable agricultural systems of the new century in the semiarid prairie. We conclude that more research is needed on the following topics. The genetic diversity of native plant cultivars needs to be established and the value of intra-cultivar genetic diversity compared to selective breeding confirmed. In addition, the geographic range of adaptation of native varieties and their role in summer and fall grazing by beef cattle need to be determined. Seed production technology to permit efficient commercialization of these species needs to be studied. For some species, this may be as simple as documenting techniques developed by individual producers while for other species, fundamental research into seed dormancy will be required. The establishment of shrub species to improve rangelands for fall and winter grazing needs further study. Changes in soil organic carbon after seeding native species on previously cropped land need to be quantified, including the impact of species type and grazing management on the rate and extent of carbon sequestration.

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USING NITROGEN BUDGETS TO EVALUATE NITROGEN USE EFFICIENCY AND LOSSES FROM BEEF PASTURE SYSTEMS

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ABSTRACT

Nitrogen (N) is important to maintain productive pastures. However, as N can move through a variety of pathways, poor N management can negatively affect air, water and soil quality. Thus, it is important to improve our understanding of the N-cycle and to manage N-use efficiency in a sustainable manner. Three field experiments were conducted from 1995-1999 at the Brandon Research Centre, in the four pasture systems on an Orthic Black Chernozemic soil. Their objectives were: i) to determine the effects of pasture type and fertilization on cow/calf production, ii) to determine N_2 fixation by alfalfa and fertilizer N recovery by grass, and iii) to quantify recycling and losses of N from cow urine using the ^{15}N mass balance approach. The four pasture systems were: alfalfa/meadow bromegrass with (A/G+F) or without (A/G-F) fertilizer, meadow bromegrass-only with (G+F) or without (G-F) fertilizer. The data from these experiments were assembled to establish N-budgets. A Transfer:Recycle:Input:Output (TRIO) budgeting approach was used to quantitatively describe N flow through the soil-plant-animal system. The objective of this exercise was to evaluate N-use efficiency, identify potential for losses, and to develop alternative management options to minimize N losses from these pasture systems.

Over the period of 1995-1999, alfalfa fixed 58 and 71 kg N/ha/year based on the estimates using the ^{15}N-enriched isotope dilution method for A/G-F and A/G+F, respectively. Based on the conservative estimates, this input could reach up to 75-92 kg N/ha if fixed N in 'below-ground' parts of alfalfa was also considered in the estimates. Amount of N_2 fixation by alfalfa in A/G+F was very comparable to average fertilizer N input (96 kg N/ha/year) in G+F. In fertilized meadow bromegrass pastures (G+F), fertilizer N recovery by meadow bromegrass from 1995-1999 averaged 47%. Total N contained in pasture forage from 1995-1998 averaged 26, 68, 72, 110 kg N/ha/year in G-F, G+F, A/G-F and A/G+F, respectively.

Animal N intake and retention in cow and calf gains were also calculated from 1995-1998. Total N intake averaged 17, 43, 40 and 56 kg N/ha/year while N retention averaged only 2, 4, 3 and 4 kg N/ha/year, and total N in excreta averaged 15, 39, 37 and 52 kg N/ha/year for G-F, G+F, A/G-F and A/G+F, respectively. An experiment using ^{15}N-labelled cow urine showed that over the one month period after urine application, only 8 and 9% of urine N was recovered in plant and soil, respectively, 83% was unaccounted for. In the soils only 1% of urine N was recovered down to the 30-60cm depth at the end of the experiment.

In this environment, N-budgets indicate that having alfalfa (40-50%) in mixed pastures can replace fertilizer N input via N_2 fixation and produce similar or more pasture protein on-offer than grass fertilized with N. Although there were large differences in total plant N production and animal N intake between the four pasture systems, N retention in cow and calf gains were small, only representing 8-11% of total animal N intake, resulting in significant quantities of N being returned back to the pastures in the form of urine and feces. In grazing systems, urine and feces, particularly urine, represent important source of N lost into the environment. The observation of low ^{15}N recovery down to the deep soil layer, together with the low level of soil nitrate (0.9-1.4 mg/kg soil) measured down to a depth of 1 m, suggests that N leaching might be limited either on a paddock scale or on the scale of individual urine spots, and that ammonia volatilisation and denitrification could represent the major pathways of N losses in this environment. These results suggest that managing cattle grazing and nutrition to achieve even excreta (urine and feces) distribution and thus enhance nutrient recycling, and to improve N-use efficiency in animal gains are essential to minimize N losses from these pasture systems.

Compared to grass fertilized with N, alfalfa-based pastures with or without fertilizer can produce comparable or higher dry matter yield and plant crude protein for grazing animals at much lower cost and with few external energy inputs. It is important that further research be conducted to quantify N losses from ammonia volatilisation and denitrification in these pastures. Since N loss through denitrification is becoming an important issue in respect to global warming and the sustainability of agriculture, a key question that needs to be addressed is: "Can alfalfa-based systems produce less N_2O per unit of animal gain than N-based grass systems in the this environment?"

EFFECT OF ENERGY SUPPLEMENTATION ON METHANE PRODUCTION BY GRAZING STEERS

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ABSTRACT

The objective of the study was to examine the effect of supplemental grain on methane (CH_4) production by grazing steers. In a completely randomized design with repeated measures, methane output was measured for 2-24 hr periods using the sulfur hexaflouride tracer gas technique, from eight Angus steers as they entered (IN) and exited (OUT) paddocks. Four steers (319.5 kg) only grazed legume/grass pastures (CON). Four steers (319.8 kg) (SUP) each received rolled barley grain during three stages (EARLY, MID and LATE) of a grazing season. Early pasture quality (ADF, IVOMD and GE) was highest ($p<0.05$). Pasture quality declined ($p<0.05$) as animals exited paddocks. Forage OMI (10.5 ±0.3 kg d^{-1}) and GEI (48.6 ±1.4 kcal d^{-1}) were higher ($p<0.05$) for CON than SUP steers (9.2 ±0.3 kg d^{-1}; 43.9 ±1.3 kcal d^{-1}). Supplementation increased ($p<0.05$) total GEI (56.9 ±1.4 kcal d^{-1}) and gains of SUP steers, however there were no differences ($p>0.05$) in CH_4 (l d^{-1} or % GEI) output between CON (310.5 ±25.9; 6.7 ±0.6) and SUP (331.2 ±24.6; 6.4 ±0.6) steers. Methane (% GEI) was lowest ($p<0.05$) from animals in early period (4.7 ±0.3) and lower ($p <0.05$) at IN (4.6 ±0.4) than OUT (8.5 ±0.4). It can be concluded that pasture quality plays a role on the extent to which feed efficiency can be improved by energy supplementation in grazing animals.

USE OF ALKANE AS A NEW TOOL FOR FORAGE-RUMINANT RESEARCH

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ABSTRACT

A 2 x 2 factorial design experiment was conducted to determine the accuracy of an alkane controlled release capsule (CRC, Captec, Australia) to predict daily dry matter intake of early (E; 5 wk, n=16) or late (L; 27 wk, n=16) lactating dairy cows fed a total mixed ration (TMR) of silage:concentrate with a ratio of either 40:60 (HC) or 70:30 (LC). Diets was offered ad libitum with intake recorded daily. Eleven days after the introduction of the capsule (C32 and C36; release of 390 mg/d of each alkane) into the rumen, a 7 day feces collection began. Cows were kept in a tie stalls to ensure complete fecal recovery. On the last day of fecal collection, grab samples was taken at 4 h intervals for 24 h. Preliminary results from 4 cows of each combination (n=16) indicated that the used of the CRC (C31/C32 ratio; Dove and Mayes., 1991) to estimate the daily dry matter intake was 115.7,111.5, 98.4 and 96.5% of the actual intake for ELC, LLC, EHC, and LHC respectively (SEM 4.2%). This result indicate an overestimation of DMI with the LC diet ($P < 0.01$) while an unbiased in prediction was obtained for cow fed with HC diet ($P > 0.05$). No effect of stage of lactation or the interaction between treatments was observed when dry matter intake was predicted ($P > 0.05$). Diurnal variation of C31/C32 fecal concentration, expressed as proportions of the mean ratio for each cow, indicated no systematic variation throughout the day as none of the values was significantly different from unity ($P > 0.05$). These preliminary results indicate that the CRC could be used to estimate dry matter intake of lactating cows used at different physiological stage but caution should be applied when diet of different silage:concentrate ratio will be fed.

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EVALUATION OF N-ALKANES AS MARKERS FOR THE ESTIMATION OF FORAGE DIGESTIBILITY IN RUMINANTS

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ABSTRACT

The objective of this trial was to compare the alkane marker technique with the total fecal collection technique for measuring dry matter digestibility (DMD) in forages or forage-concentrate mixtures. Eight Holstein steers weighing approximately 208 " 19.2 kg were assigned to four dietary treatments in a three period cross over design based on body weight. The four dietary treatments were 1) 100% meadow brome grass hay (B); 2) 50% B + 50% alfalfa hay (BA); 3) 50% B + 50% barley grain (BB); and 4) 25% B + 25% alfalfa hay + 50% barley grain (BAB). The two types of hay were chosen to achieve a wide range of hydrocarbon intake. Appropriate portions of forages and grain were mixed as total mixed rations and fed in two equal portions twice daily at 2.5% of body weight. Animals were given oral administration of an n-alkane bolus (C_{32} and C_{36}) on day 1 of each period (30 days). Total feces was collected daily from day 8 to 16 of each period. N-alkanes was separated from the diets and feces by overnight saponification with alcoholic KOH followed by extraction with n-heptane. Dry matter digestibility (DMD) was calculated using the feed:feces ratio of each marker. Addition of barley to the diets resulted in a higher DMD for BB and BAB diets by both methods. The DMD by total collection was 57.3, 57.8, 67.2 and 69.3% for B, BA, BB and BAB diets, respectively. Fecal recovery of plant alkanes was low, ranging 66.8 to 76.3% across diets, whereas fecal recovery of dosed alkane C_{32} and C_{36} was 106.6 and 98.0% respectively for all diets. The estimated DMD using C_{33} as a marker was 35.8, 40.1, 53.0 and 59.7% for B, BA, BB and BAB diets, respectively. The fecal extraction procedure must be modified to ensure recoveries approach 100%.

July 20 / 20 juillet 2000
13:30 to 15:00

Session 3: Forage Production and Conservation

Thème 3: Production et conservation des fourrages

Moderator / Modérateur: Doug May

GRAZING TOLERANCE IN ALFALFA: CULTIVAR EVALUATION ACROSS DIVERSE ENVIRONMENTS

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ABSTRACT

Beef and dairy producers have long recognized the feed value of alfalfa-rich pastures. But two problems have historically stood in their way – bloat and a lack of persistence under grazing. The introduction of "bloat-reduced" and/or "grazing tolerant" alfalfa cultivars may open the door for more profitable beef production. Many of the experimental genotypes being developed are "dual-purpose" varieties (hay or graze) featuring high quality, multiple disease resistance, high yield, and grazing tolerance. The big question that remains is, under the climatic conditions of the northern Great Plains, will grazing stress lead to poor plant persistence.

A comprehensive grazing trial was initiated in 1996 at Lethbridge, AB; Swift Current, SK; Brandon, MB; and in 1997 at Mandan, ND. A collection of 23 alfalfa cultivars and experimental lines was evaluated in a 3 year grazing experiment assessing persistence in pure stands and in mixture with meadow bromegrass under both continuous and rotational stocking. Different soil types and extremes in moisture and temperature provided adequate data to compare genotypes across the diverse environments.

Separation among persistent cultivars was initially observed in the spring of 1999 in Swift Current, SK and Brandon, MB while the other two sites showed moderate losses under continuous stocking only. Severe losses under both rotational and continuous stocking systems in Brandon, MB and Swift Current, SK strongly suggested that persistence under grazing in the northern Great Plains is inextricably linked to winterhardiness. As expected, the grazing intolerant check, Apollo (according to the standard protocol of the North American Alfalfa Improvement Conference) has not persisted well at all sites after two grazing seasons. However, unexpectedly, the grazing tolerant check, Alfagraze, suffered widespread losses in Brandon, MB and Swift Current, SK. In general, alfalfa varieties and experimental lines well adapted to grazing stress in central and southern US (e.g. Alfagraze) have failed to demonstrate a superior advantage over well adapted hay-type cultivars of western Canada (e.g. Beaver, Anchor, Barrier). In contrast, alfalfa varieties of the subspecies *falcata* (e.g. SCMF 3713) or containing high *falcata* parentage (e.g. Rangelander, Spredor II, Rambler) have persisted extremely well at all sites.

EFFECT OF MULTI-YEAR APPLICATION OF DAIRY SLURRY AND FERTILIZER: PERSPECTIVES ON CROP RESPONSES, SOIL NUTRIENTS, SOIL ECOLOGY AND N_2O EMISSIONS

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ABSTRACT

The long-term effects of using manure as the principal nutrient source in intensive crop production systems are not well known. This paper reports on the effects of multi-year application of fertilizer or dairy slurry on a tall fescue (*Festuca arundinacea* Schreb.) sward. Slurry sustained greater grass yield than chemical fertilizer. Unlike fertilizer, slurry supplied 70 to 120 kg N/ha one year after application but little after one year; 4-years of manure applications built up the stable organic matter pool in the soil. Manure-N was less prone to leaching but more prone to N_2O emissions than fertilizer-N. Manured soils had considerably more biological activity than fertilized soils. High rates of manure application increased soil P.

INTRODUCTION

The Fraser Valley in British Columbia has many high-input dairy farms that produce large quantities of liquid manure. Liquid manure can be used as the sole source of nutrients for forage grass without loss of production (Bittman et al. 1999). For the same immediate crop response as fertilizer N, manure has to be applied at equivalent rates of inorganic N. Although addition of organic C and N is known to enrich soil, alter soil biota and increase potential mineralization or immobilization, the long-term effects of using manure as the principal nutrient source in intensive production systems are not well known. Previous work has shown surprisingly large differences in N supplying capacity among apparently similar grassland soils and that these soils also have substantial capacity to immobilize mineral N (Bittman and Kowalenko 1998). Accurate predictions of nutrient requirement are important because farmers must produce the maximum amount of crop while preventing nutrient loss to the environment.

This paper reports on the effects (in 1998) of applying fertilizer or dairy slurry for several years on a perennial grass sward with respect to crop yield and persistence, soil nutrients, populations of soil microbes and invertebrates, and N_2O emission.

MATERIALS AND METHODS

The study, initiated in 1994, occupied 120 x 150m of permanent tall fescue (*Festuca arundinacea* Schreb.) on a medium texture alluvial soil at Agassiz, BC. The basic experiment had 10 treatments (shown below) and 4 replicates arranged as a randomized complete block. The 'low' and 'high' rates were nominally 50 and 100 kg ha^{-1} of inorganic-N applied for each harvest (4X per year) as NH_4NO_3 with other minerals as needed (F), or liquid dairy manure with sawdust bedding (M). Each plot was 3x150m; the manure was applied with a 3-m wide 'drag-shoe' applicator. Manure in 1998 averaged 91.7% water, 13.4:1 C:N, 6.7 pH and, on wet basis, 0.16% NH_4-N, 0.31% total-N, 4.1% C. Manure applications started in different years so the treatments involved different lengths of time that fertilizer or manure was applied.

Treatment	1994	1995	1996	1997	1998
Control	0	0	0	0	0
Fertilizer (high and low)	F	F	F	F	F
Manure1 (high and low)	F	F	F	M	M
Manure2 (high and low)	F	F	M	M	M
Manure4 (high and low)	M	M	M	M	M
Fert/Man[1](high)	FM[1]	FM	FM	FM	FM

[1] Fertilizer and manure alternated each application.

The cumulative effects of the 1994-97 treatments were also evaluated in 1998 by superimposing (i) no nutrients, (ii) manure at high-N on a portion of the original treatments.

The crop was harvested and sampled annually in May, July, August, and Sept.-Oct. Plant-N concentration was determined by dry ashing (LECO FP428). Grass ground-cover was determined in March with a line transect. Soil samples (0-0.15, 0.15-0.30 and 0.30-0.60m depths) were taken at each harvest; NO_3 and NH_4 were extracted with KCl and analyzed with a FIA. Other soil nutrients were analyzed by ICP on «Kelowna» extracts. Total soil C and N were determined by dry ashing (LECO CNS2000). Soil bacteria, protozoa and bacteriophagous nematodes were counted in 0-0.3m soil samples taken 1 and 3 weeks after manure application. Soil solution was collected with suction lysimeters (0.6 and 0.9m depth) after rainfall events from March 1, 1998 to Feb. 28, 1999 and NO_3-N-concentrations determined with FIA. N_2O was measured by gas chromatography in samples from 0.7x0.7 m vented chambers taken twice per week for 4 weeks after treatments were applied. Carabid ground beetles were sampled using pitfall traps for 1-week periods every month from April-October. Earthworms were collected from the soil surface of two replicates in early April 1999 after pouring a solution of cured hot mustard (53g/7L water) on 50x50 cm quadrats.

RESULTS AND DISCUSSION

At similar rates of applied mineral-N, the manured plots yielded more than fertilized plots (Table 1). At similar rates of applied total-N, high-F plots yielded the same but took up more N than the low-M treatments. Yield increased with years of manure application at the low- but not the high-N rate. High-M reduced grass cover relative to low-N rates. Decline in manured swards in this trial was not due to wheel traffic as is often suspected on farms.

Residual soil NO_3-N in Oct. was negligible in control and low-N plots but 40 and 120 kg/ha in high-M4 and high-F plots, respectively (Table 1). Soil solution NO_3 was much greater in high-N than low-N plots and slightly higher in high-F than high-M4 plots. These findings are surprising because twice as much total-N had been applied on the manured than fertilized plots over 5 years, suggesting that more N was immobilized in manured than fertilized plots. Indeed, the 0-15 cm soil layer in the M4 treatments contained significantly more total-N and C compared to control and F treatments. Since residual soil NO_3 in Oct. is likely to leach over-winter, manure is less likely to cause leaching than fertilizer. Most N_2O was emitted in the 2-weeks after nutrient application, especially in summer. In the day after application, emissions averaged 5-60 and 15-400 ng N_2O-N/m^2/s for the low- and high-N treatments, respectively. Soil P was greater for high rates of manure than fertilizer or control treatments.

Manure significantly increased populations of bacteria, relative to fertilizer and control plots (Table 1). Manure also increased numbers of protozoa and bacteriophagous nematodes which mineralize N tied up in microbial biomass. There was also evidence of increased activity of several soil nutrient mineralizing enzymes in the heavily manured plots and a concomitant decrease in the heavily fertilized plots (data not shown). Of thirteen carabid species found, *Pterostichus melanarius* (Illiger) comprised 85% of the population, with numbers positively related to N-rate in the 4-year treatments (r^2= 0.45). This suggests that high levels of applied N provided long-term habitat enrichment that attracted the beetles or enhanced their reproduction. Earthworm numbers (and biomass) were collectively higher in manure treatments than in fertilizer treatments.

Where a 'no-nutrient' treatment was superimposed in 1998, yield and N-uptake of previous F plots were similar to controls (Table 2). In contrast, low-M plots yielded 4 t/ha and took up 75 kg/ha more N than controls, and high-M plots yielded over 5 t/ha and took up over 125 kg/ha more N than control. Amount of N supplied by previous manure treatments was similar for one year as four years, suggesting that most of the N came from the manure applied in the previous year. The manure-N remaining from two or more previous years appears stable. Where a high rate of manure was superimposed on the previous treatments, there was much more residual NO_3 on the previous high-M4 than the high-F treatment, suggesting that the source of N influences the quantity of soil NO_3 in autumn. For the 'no-nutrient' superimposed treatment, quantities of residual soil nitrate were small regardless of previous treatments.

CONCLUSION

This study showed that dairy slurry sustained greater yield of perennial grass than chemical fertilizer and that 4-years of manure applications built up the stable organic matter pool in the soil. Manure supplied 70 (low rate) to125 (high rate) kg N/ha the first year after one or more years of application. Manure-N was less prone to loss by leaching than fertilizer N. Manured soils had considerably more biological activity and N_2O emissions than fertilized soils. High rates of manure application increase soil P which suggests the need to remove some high-P solid fraction prior to spreading.

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Table 1. Effect of fertilizer and manure applied at two rates for different numbers of years (see Materials and Methods) on crop, soil nutrients, soil microbes and soil invertebrates in 1998.

	-Crop Parameters-			----------Soil Nutrients----------							-----Soil Microbes-----			----Invertebrates---	
	Grass Cover	Yield	N-Uptake	Residual nitrate (Oct.)	Apparent N-Uptake from Applied N	Soil P concentration	Total soil C (0-0.15m depth)	Total soil N (0-0.15m depth)	Nitrate in Soil Solution (0.6m)	Nitrate in Soil Solution (0.9m)	Bacteria ($x10^6$)	Protozoa	Nematodes (bacteriophage)	Mean *P. melanarius*	Mean Earthworms
Treatment	**%**	**t/ha**	**kg/ha**	**kg/ha**	**kg/ha**	**g/kg**	**%**	**%**	**mg/kg**	**mg/kg**	**cells/ g soil**	**cells/ mg soil**	**/100g soil**	**/trap**	**/quadrant**
Control	65	8.9	155	0	---	137	3.45	0.29	0.1	0.0	600	168	246	24.0	29.5
Low-N															
Fertilizer	72	14.1	297	0	142	133	3.21	0.27	0.2	0.1				29.5	25.0
Manure 1	76	15.0	295											51.5	37.5
Manure 2	72	15.3	319						0.2	0.3				32.5	36.5
Manure 4	73	16.1	338	2.2	117	156	3.82	0.31	0.9	0.3	763	263	1017	26.2	30.5
High-N															
Fertilizer	69	15.5	420	119.9	392	130	3.56	0.30	4.0	4.6	521	107	268	27.2	22.5
Manure 1	61	18.3	450						2.2	3.1				36.5	31.0
Manure 2	59	18.1	468						2.6	4.3				41.2	54.0
Manure 4	58	17.6	457	41.7	223	188	3.81	0.31			931	533	1092	38.0	41.5
Fert./Man [1]	63	17.9	481											33.8	37.5
LSD (0.05)	9	0.9	29	33.7		25	0.29	0.02	1.3	2.3	128	125	175	19.3	21.8

[1]Fertilizer and manure alternated for each harvest.

Table 2. Yield, N-uptake, and residual soil NO_3 (in Oct.) in a tall fescue sward as affected by 'no-nutrient' and 'high manure' treatments superimposed in 1998 on fertilizer and manure treatments applied 1994-97.

	——No Nutrient in 1998——			——High-N Manure in 1998——		
	Yield	N-Uptake	Residual NO_3 in soil	Yield	N-Uptake	Residual NO_3 in soil
Previous Treatment	t/ha	kg/ha	kg/ha	t/ha	kg/ha	kg/ha
Control	6.36	113	0.0	13.0	329	15.4
Low-N						
Fertilizer	6.75	123	0.0	13.1	327	14.6
Manure 1	10.11	189		14.6	370	
Manure 2	10.30	196		14.7	370	
Manure 4	10.13	186	0.1	14.2	365	35.6
High-N						
Fertilizer	6.93	129	0.0	12.3	326	25.7
Manure 1	11.90	229		14.6	381	
Manure 2	12.01	238		14.4	391	
Manure 4	11.72	241	6.4	13.6	359	108.3
Fert./Man.[1]	11.52	223		14.9	370	
LSD (0.05)	1.07	30	3.7	1.1	30	37.6

[1]Fertilizer and manure alternated for each harvest.

INTENSIVE MECHANICAL CONDITIONING OF FORAGES: A REVIEW

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ABSTRACT

Intensive forage conditioning, also known as maceration, has been the object of research at several sites around the world over the last twenty years. Maceration has been shown to increase the field drying rate, to enhance the rate of acidification of silage and to improve, in some instances, the dry matter intake or digestibility of forages fed to ruminants. In other instances, however, maceration has been shown to cause more losses and result in a lower quality feed than forages treated with conventional conditioning, especially under rainy or humid wilting conditions. The paper reviews some of the mechanisms that have been developed for intensive mechanical conditioning of forages and several experimental results of field drying and power requirement. The paper provides some explanation for variable animal response with macerated forage. Finally, a perspective on the future potential use of intensive forage conditioning is presented.

INTRODUCTION

Forage field losses tend to increase with prolonged field wilting (McGechan, 1988). To reduce these losses, researchers have proposed various approaches to reduce the field wilting time. Thermal treatments such as heated rolls, heated air injection or microwaves provide direct heat for water evaporation (Khalilian et al. 1992) and have been shown to improve the feed value by reducing proteolysis (Charmley and Veira, 1990). Chemical treatments such as potassium carbonate solutions pulverized over the surface of the crop maintain the stomata open for a prolonged period of time after mowing, thereby facilitating natural water evaporation (Rotz, 1985). However, mechanical treatments such as roll conditioning (Rotz and Sprott, 1984; Shinners et al., 1991; Borreani et al., 1999) are generally more practical and more economical than thermal or chemical treatments. Novel mechanical conditioning treatments can be more easily adopted when they are integrated in a machine already used on the farm, such as a mower, or become available in a form similar to other machines already used, such as tedders, windrow inverters or rakes.

Very intensive mechanical conditioning, also known as maceration, has been the object of research at several sites around the world over the last two decades. Krutz et al. (1979) proposed an intensive forage conditioning concept that consisted of two corrugated steel rolls turning at high, but different speeds with a narrow clearance between the rolls. The peripheral speed difference caused a shearing effect on the crop, considerable cell rupture, a release of intracellular water and extremely rapid

water evaporation. To minimize the loss of detached leaves and nutrient-rich juice, the macerated forage was compressed into a thin mat (about 5 to 10 mm thick) which was deposited delicately onto the stubble. Forage juice extracted during conditioning was channelled on top of the mat where soluble nutrients would dry and be retained. Related patents were obtained by Krutz (1979, 1981), Cicci (1982) and Holdren (1982). These patents covered the concept of intensive mechanical conditioning of forages but did not provide enough detail to develop effective mechanisms that could be applied in field working machines.

Since then, several prototype macerators have been developed and evaluated under various conditions. The objective of this paper is to review some of the engineering developments, to summarize the impact of maceration on the feed value of forages and to discuss future perspectives for intensive mechanical conditioning of forages. The review emphasizes developments and potential applications under Canadian conditions.

ENGINEERING DEVELOPMENTS

Macerator Design

Three types of designs have received most attention: the peripheral roll macerator, the staggered roll macerator and the crushing-impact macerator (Figure 1).

Peripheral roll macerator. This design was developed by a research group in Wisconsin (Koegel et al., 1988). A field working prototype consisted of a 1.2 m wide cutterbar, a 0.7 m wide maceration unit composed of seven small (0.1 m diameter) peripheral rolls turning around a larger (0.4 m diameter) central roll, and a belt-and-drum press to form the mat. Field evaluation showed that the wilting time to dry down alfalfa to a moisture below 20%, i.e. a level considered safe for hay conservation, could be reduced to less than 6 h with the macerator (Shinners et al., 1987). This was a considerable improvement compared to the typical 3-d time period required in Wisconsin with conventional haymaking equipment. The peripheral roll macerator design was also evaluated by other researchers, notably in Germany (Schurig and Rödel, 1989; Bischoff et al., 1989) and Turkey (Öztekin and Özkan, 1997).

Several technical issues were raised as a result of the use of a very intensive mechanical conditioning. It was important to press this highly bruised material into a cohesive mat (see below) to minimize handling losses. Shinners et al. (1988a) compared various numbers of rolls and roll speed ratios to optimize the process in terms of maceration effectiveness and energy requirement. They suggested five planetary rolls and a speed ratio of 1.5:1. A commercial attempt was made to introduce the peripheral roll macerator in the early 1990's (Schmittbetz and Liebers, 1991; Deutz Fahr, 1993) but was unconclusive.

Staggered roll macerator. This design was also developed in Wisconsin but first reported and evaluated in Québec as a result of collaborative work with the Wisconsin group (Savoie and

Beauregard, 1991a). A field mower-macerator prototype was built in 1991 and composed of a 2.1 m wide cutterbar, eight staggered rolls and a belt press (Savoie et al., 1993a; Figure 2). This machine increased the field drying rate of alfalfa by an average 137% and of timothy by 61%.

The staggered roll design was simpler in terms of roll fabrication than the peripheral roll design because all rolls could be of the same diameter. The Prairie Agricultural Machinery Institute in Manitoba developed a simple two-roll staggered macerator adapted to a cutterbar mower (May, 1994; PAMI, 1994; 1996). It was very efficient in terms of drying rate increases for alfalfa under the relatively dry conditions of Manitoba.

Under more humid conditions in eastern Canada, Savoie et al. (1997) developed a four-roll staggered macerator for a disk mower (Figure 3). They obtained relatively high throughputs and good drying rate increases in the field. Subsequently, the same research group in Québec developed a three-roll staggered macerator adapted to a 4.2 m wide cutterbar for a self-propelled mower-macerator (Savoie et al., 1999a; Figure 4). These prototypes indicated the possibility of adapting the staggered roll design for large throughputs above 50 t of fresh crop per hour. They also represented a less intensive maceration level compared to the peripheral roll macerator, but they allowed forming windrows without the need to compress into a thin mat. There was practically no difference in terms of field loss between compressed and uncompressed windrows which had been macerated with three rolls (Savoie et al., 1997). A patent was recently obtained for a three-roll macerator (Savoie and Lajoie, 2000) but this configuration has not yet been developed commercially.

Crushing-impact macerator. This type of macerator was proposed as a simpler alternative to the peripheral roll macerator (Kraus et al., 1990; 1992; Koegel et al., 1992a). It consisted of two crushing rolls and an impact rotor (Figure 1c). The forage was broken into ribbon-like fibre as it struck the rotor. The researchers observed that this design required considerably less energy than the peripheral roll macerator for a similar level of conditioning. A patent was obtained for the crushing-impact macerator (Koegel et al., 1992b).

Impact maceration, without crushing, was attempted commercially (Krone, 1993) as a windrow handling treatment to be applied after mowing. Crushing maceration, without impact, was proposed by Nishizaki et al. (1997). It was obtained with four pairs of crushing rollers that exerted a high pressure on the fresh crop to break the stems longitudinally. However, none of these crushing or impact macerators have been further developed into a large capacity field machine.

Mat forming system

Because maceration destroys the physical integrity of the stems, frees up juice and detaches leaves, it was necessary to develop a compression device to agglomerate the bruised mass into a cohesive mat. The objective of the mat forming system was to place the macerated forage on the stubble for rapid wilting and subsequent handling without important losses. Work carried out in the early 1980's in Wisconsin used either a platen press or a roll press to study the wet strength and the drying rate of macerated forage mats (Risser et al., 1985; Shinners et al., 1985). A number of other press

designs were developed subsequently with the objective of forming a cohesive mat continuously during mowing-maceration.

Belt press. The basic idea of a belt press can be visualized in Figure 2. The macerated forage is conveyed onto a wide belt (typically 1.2 m or wider). A second belt of the same width moving in the same direction converges against the first belt to compress the forage mass into a thin layer (typically 5 to 10 mm thickness). The two belts are compressed by moving together between a series of tensioned rolls. Eventually the two belts separate and the compressed forage mat is released onto the stubble. Usually, an escape route is required for excess moisture produced during compression. One proposed escape route is the use of perforations in one of the belts and deflection of the juice either back onto the freshly macerated forage or on top of the mat as it is deposited onto the stubble.

Wheel press. A series of parallel wheels can be used to compress macerated forage. The forage moves on a conveyor and is compressed as it passes over a large roll of constant central axis. A series of parallel wheels is pushed down over the macerated forage and exerts a pressure to form a mat. The pressure can be varied to obtain mats of various thicknesses.

Slatted conveyor press. A slatted conveyor press is made of two conveyor belts composed of rigid slats (Figure 3). The bottom conveyor moves around rolls of constant central axes. The upper conveyor also turns around rolls of constant central axes. The macerated forage is fed between the two conveyors while press plates, positioned within the upper conveyor, compress the forage. This system requires a low friction coefficient between the press plates and the rigid slats, usually made of smooth plastic. Savoie et al. (1997) observed that such a press could be used to form a mat but worked best with a hydraulic power system and an oil droplet spreading system to maintain excellent lubrication and minimize friction between the press plates and the moving slats.

No press. The design of a high capacity press system is not a trivial matter. One problem is the relatively high power required. For example, Savoie et al. (1997) estimated a hydraulic power requirement of 13.1 kW for compression when the dry matter flow rate was 6.7 t DM/h, i.e. a specific energy requirement of about 2 kW.h/t DM. Another problem, especially with the belt-type press, is the requirement of a belt guidance device because of strong lateral forces that occur under non-uniform forage flow.

Because of these difficulties, May (1994) and Savoie et al. (1997) suggested that a slight reduction of the maceration intensity could eliminate the need for a compression system. The more lightly macerated material could be left in a fluffy windrow and would dry as well as a compressed mat, without significant differences in field dry matter losses.

Technical assessment of forage maceration

Field drying. Table 1 reports ten different comparisons of the field drying rate of macerated forage versus a control. In all cases, the drying rate was increased after maceration, with increases ranging from 26% to 160%. Increases tended to be higher over short wilting periods (6 to 9 h) and to be

lower over longer wilting periods (30 to 34 h). One exception was the persistently large drying rate increase (+125%) observed over a 50 h period in Manitoba with alfalfa exposed to a relatively dry environment (May, 1994). The field drying rate improvement is especially good under sunny, good drying conditions. The macerated windrows lose water rapidly in the early stages of drying. Over a longer wilting time, the night-time interval attenuates the advantage of maceration. Dew or rain absorption tend to be higher in the macerated crop and can eliminate any previous drying advantage. The number of maceration rolls and the complexity of the machine does not seem to have a major effect on the drying rate increase across environments.

The density of the swath is an important factor in the drying rate. Spreading forage over as wide an area as possible increases the absorption area of solar radiation either for conventional swaths or macerated swaths. Savoie et al. (1992) suggested that the density of macerated alfalfa should not be greater than 0.45 kg dry matter/m^2 for the forage to be able to dry down to less than 20% moisture in a day with sunshine. If the yield is greater than 4.5 t DM/ha, then it is impossible to spread enough the material to reach that goal. With ryegrass, Savoie et al. (1994) also observed a rapid drying rate when the swath density was relatively low at 0.4 kg DM/ha; dry hay could be obtained after energy absorption equivalent to a pan evaporation of 5 mm. Maceration is more effective in a low yielding crop that is well spread out in the field, as suggested by McGechan et al. (1991).

Power requirement. Table 2 reports the specific energy to operate macerating rolls from six different prototypes. The 7-roll peripheral macerator required the highest level of energy (9.2 kW.h/t DM). The crushing impact rolls and the staggered rolls had similar energy requirements which ranged between 2 and 4 kW.h/t DM. Beside energy for maceration, additional energy may be required to form a mat which was estimated as about 2 kW.h/t DM for the slatted conveyor press (see above). The total energy to macerate and compress can become a limitation, especially at high mowing rates.

Conventional mowing-conditioning requires a relatively small amount of power or energy. On the one hand, the power is sometimes expressed only per unit mower width, independently of forward speed and mass flow. For example, ASAE (1999; Engineering Data D497.4) suggests 4.5 kW/m for a cutterbar mower-conditioner and 8.0 kW/m for a disk mower-conditioner. On the other hand, the power required for mowing-conditioning has been reported in energy per unit mass. Rotz and Sprott (1984) reported values of fuel consumption ranging between 0.24 and 0.84 L/t DM, which are converted approximately to a range of 0.75 to 2.5 kW.h/t DM. The cutterbar-roll conditioner had the lowest energy requirement (0.75 kW.h/t DM) and a disk-flail conditioner had the highest (2.5 kW.h/t DM). A typical 60 kW tractor with 40 kW available to the power takeoff (PTO) can therefore mow and condition over 15 t DM/h, i.e. 3 ha/h or 75 t fresh crop yielding 5 t DM/ha at 80% moisture. If maceration and mat forming require an additional 4 kW.h/t DM, an extra 60 kW at the PTO would be needed to maintain the same high mass-flow-rate. Otherwise the mass-flow-rate will have to be decreased by as much as two thirds. Therefore, reducing the number of macerating rolls and reconsidering the need for compression into mats are important issues in designing a practical mower-macerator when available power is a constraint.

Other technical issues. Roll surface has not been the object of much research. The typical surface

of peripheral or staggered rolls is formed of a series of longitudinal grooves with pointy or slightly flattened apexes (Figure 5). Savoie and Tremblay (1997) reported an experiment using a helically grooved roll in conjunction with two longitudinally grooved rolls. This configuration (one helically grooved roll and two longitudinally grooved rolls) produced a drying rate similar to the one obtained with a macerator composed of three longitudinally grooved rolls. Both configurations increased the drying rate by 85% compared to an unmacerated control. The helically grooved roll is interesting because of its lower fabrication cost compared to a longitudinally grooved roll. However, further evaluation would be required to optimize the roll surface versus the cost of fabrication of the rolls.

Another technical issue is the hardness and durability of the roll surface. Since most field prototypes have been used only for a limited time, there is not enough data at this stage to compare various roll surfaces and their durability. There is empirical evidence with soft iron rolls that the apexes become dull and rounded within 100 to 200 hours of use. Therefore, a process of steel hardening should be applied to macerating rolls to prolong their useful life to that of typical mower-conditioners, i.e. 1000 to 2000 hours.

The development of various maceration prototypes in different countries has made it difficult to compare results because of differences in the level of mechanical conditioning. A number of methods have been proposed to quantify mechanical conditioning: diffusion of K^+ ions in a water solution (Locus et al., 1994), compressibility of forage under a fixed pressure (Savoie et al., 1996a) and the electrical conductivity of leachate obtained from the conditioned forage (Kraus et al., 1999). As the forage is increasingly macerated, ions and soluble constituents are more easily released. Similarly, the forage is more easily compressed. There is not a single, standard method currently used to assess the level of mechanical conditioning. However, the development and acceptance of such a standard method would facilitate comparison of intensive forage conditioning treatments at various sites.

The pick-up of macerated windrows has been a concern because of potentially large losses. The broken nature of the particles and the fragility of mats required a delicate pick-up system. Straub et al. (1989) suggested a belt pick-up unit instead of the traditional tyne pick-up unit. Savoie et al. (1993a) did not find significant differences in pick-up losses between the two systems. A reduction of the intensity of maceration has also been found to alleviate the fragility of the macerated windrow and the concern with pick-up losses.

Maceration was initially developed as an integral part of the mower to combine mowing and intensive conditioning in a single operation. Because maceration may be highly beneficial under good drying conditions, and may be deleterious under rainy conditions, it should not be applied systematically, especially in an area with variable climate. For this reason, Descôteaux and Savoie (1999) developed a pull-type macerator that could be applied after mowing as an independent operation (Figure 6). Such a macerator presents a dual advantage: reduced cost to adopt maceration (less costly than a mower-macerator) and the possibility of applying maceration as an optional treatment, only if weather forecasts are favorable. In the long run, however, it seems more efficient to integrate maceration with the mower and to develop a hydraulic control that would modify the

level of maceration according to the crop processed and the weather forecasts.

Another technical issue is the collection of forage juice during the mowing-maceration process. Forage juice can be processed into various components that may be sold on high value markets such as soluble protein for monogastrics, xanthophyll and beta-carotene (McGuckin et al., 1982). Maceration and compression into a mat have been shown to extract up to 15% of the fresh mass (Savoie and Beauregard, 1991b). If there is a market for forage juice and extracted products, maceration-compression can be used as a first step for collecting the juice in the field. However, if there is no market for such extracts or if the economics are not favorable, then the forage juice is best valued by simply returning it onto the forage. One design, that includes a perforated belt (Figure 2), redirects the juice on the top surface for retention of soluble nutrients in the windrow (Savoie et al., 1993a).

FEED VALUE OF MACERATED FORAGES

Forage quality

Maceration can affect the forage quality in several ways: increased mechanical loss by shattering, reduced respiration loss as a result of rapid drying and lower moisture content, increased leaching loss from the bruised surface if it is exposed to rain, and improved lactic fermentation of silage. This section considers some of the experimental results showing the effect of maceration on forage quality. The following section considers the effect on animal performance.

Effect of maceration on mechanical loss. Maceration can break leaves and stems into small particles which become more susceptible losses. When the macerated windrow is subsequently turned, raked or picked up by a baler or a forage harvester, each manipulation can be the source of further mechanical loss. For this reason, windrow handling should be reduced to a minimum of delicate operations.

Savoie et al. (1993a) observed 3.5% dry matter (DM) loss from forage treated with a conventional mower-conditioner and 7.8% for forage treated with an 8-roll staggered macerator. Savoie et al. (1997) observed 6.6% DM loss for conventional mowing-conditioning and 7.2% DM loss for macerated forage with a 3-roll staggered macerator. These authors did not distinguish the proportion of leaves versus the proportion of stems that were lost, but hypothesized that a much greater proportion of leaves was lost compared to stems. This hypothesis is supported by the fact that the quality based on the chemical composition almost always decreases after maceration compared to a control (see below, chemical composition). The feed value of leaves is considerably greater than that of stems. For example, alfalfa leaves contain about 35% crude protein (CP) and 20% acid detergent fibre (ADF) while stems contain 14% CP and 50% ADF (Savoie, 1988). A greater loss of leaves will decrease the protein content and increase the fibre content of the harvested forage.

Effect of maceration on respiration and leaching loss. Maceration creates a large exposed area for

microorganisms to grow on and releases rapidly some of the intracellular soluble sugars, a substrate used for the growth of microorganisms. In the very early stages of field drying, the respiration rate can be increased as a result of maceration. However, since maceration can also increase the drying rate, the amount of water needed for the growth of microorganisms becomes limiting more rapidly than in a conventionally conditioned crop. Therefore, maceration followed by rapid drying will actually inhibit crop respiration.

If maceration is followed by slow drying due to rain or humid conditions, then respiration will actually be increased. Maceration will produce an increased area for microorganisms to grow on and will facilitate the release of soluble sugars, without the constraint of limited water if the weather remains humid and prevents drying.

A small number of experimental studies have confirmed this ambivalent effect of maceration on respiration and leaching losses. Rotz et al. (1991) observed that rain caused greater loss on macerated alfalfa than on unmacerated alfalfa. After 18 mm of rainfall, they estimated 15% DM loss in macerated alfalfa, and only 4% DM loss in rubber-roll conditioned alfalfa. After 62 mm rainfall, DM losses were 27% and 7%, respectively. Savoie et al. (1993b) also noted more losses in macerated alfalfa (20%) than in unmacerated alfalfa (13%) after 6 mm of rain. Timothy grass was less affected by loss after rain (8% if macerated, 7% if unmacerated). When no rain occurred and drying conditions were excellent, respiration loss of alfalfa windrows was actually lower: 5% for macerated alfalfa and 12% for unmacerated alfalfa (Savoie et al., 1993b). The same study reported 0% loss for macerated timothy and 2% for unmacerated timothy under excellent drying conditions. Sundberg and Thylen (1994) observed that rain caused 1 to 2% loss of DM in conventionally conditioned forage. After maceration, they observed about 10% DM loss for grasses and 20% DM loss for legumes subjected to 18 or 25 mm of rain.

Kraus et al. (1998) measured the carbon dioxide over a 48 h period from alfalfa incubated at two temperatures (11°C and 31°C) and two moisture contents (about 79% and 55%). At low temperature and high moisture, the DM loss was 1% for macerated forage and 2% for unmacerated forage. At high temperature and high moisture, the DM loss was 14% for macerated alfalfa and 6% for unmacerated alfalfa. When alfalfa was drier (55% MC), losses were considerably lower with generally less difference between macerated and unmacerated crops. These data confirm that maceration will cause greater respiration when the crop is wet and exposed at a high ambient temperature, while at a low temperature and low moisture content, respiration will almost cease.

Effect of maceration on silage fermentation. Studies by Muck et al. (1989) and Bischoff et al. (1989) indicated that maceration accelerated pH decline in chopped alfalfa and grass silages as a result of greater growth rate of microorganisms, faster availability of soluble sugars and more rapid production of organic acids during the early stages of fermentation. Maceration also facilitated the natural compaction of chopped forage and the evacuation of a large proportion of oxygen originally present, especially in tower silos (Shinners et al., 1988b). Savoie et al. (1996b) also observed a faster decline of pH in the early hours after wrapping macerated forage in large round bales conserved as silage.

Charmley et al. (1997) found a very high count of colony-forming units (cfu) for wilted and macerated alfalfa at the time of ensiling. They observed 10^8 cfu/g of silage after maceration and wilting (35% DM), compared to 10^3 cfu/g of silage for unmacerated, wilted forage (26% DM). The pH decline was faster in the macerated silage. The macerated silage had a higher proportion of lactic acid over total organic acids (56% vs. 50%), indicating a higher degree of homolactic fermentation after maceration. However, when forage was not wilted but stored very wet (15% DM), maceration also increased microorganism activity but this included heterolactic fermentation and a lower proportion of lactic acid (47%) after maceration than without maceration (52% lactic acid/total acids). Very wet silages are known to favor clostridia and other microorganisms (McDonald et al., 1991), so maceration without wilting will result in a lower silage quality .

Effect of maceration on overall chemical composition. Table 3 presents the forage fibre content of macerated and unmacerated (control) forages in seven different experiments. In general, fibre concentration increased after maceration, especially when rain occurred during wilting. When drying conditions were ideal, e.g. under full sunshine or in the laboratory without rain (Savoie et al., 1993b; Agbossamey et al., 1998), maceration accelerated drying, reduced more rapidly the moisture content in the crop, reduced respiration activity, minimized the loss of soluble sugars and maintained a relatively low fibre content.

Maceration has been reported to reduce proteolysis, i.e. enzyme activity that degrades protein into amino acids. The inhibition of proteolysis is explained by the more rapid reduction of moisture content which reduces protease activity. Agbossamey et al. (1998) observed that alfalfa and timothy, dried in the laboratory under ideal conditions, had less soluble N (mainly amino acids) and more slowly degradable N (true protein) after maceration compared to a control. They observed similar results with alfalfa conserved as silage. Maceration further inhibited protease activity in the silo because of a lower moisture at ensiling.

Under ideal wilting conditions, maceration is expected to result in very rapid drying and lower respiration and protease activity. However, under humid or rainy conditions, maceration will increase the field respiration and protease activity, thereby increasing the loss of soluble sugars and the degradability of true protein. Therefore, maceration can be observed to either improve or reduce the feed quality of forages depending on the environment.

Animal performance

Table 4 presents a summary of eleven animal experiments where four types of ruminants (dairy goats, dairy cows, sheep or steers) were fed various macerated forages (alfalfa, timothy, ryegrass or orchardgrass) compared to a control, unmacerated forage. In five experiments, macerated forage resulted in better animal performance (more milk production, greater dry matter intake (DMI) or improved gain to feed ratio). In the six other experiments, macerated forage did not show any significant improvement. In two cases (Petit et al., 1997; Charmley et al., 1999 - chopped silage), maceration caused a significant decline of DMI but resulted in an improved gain to feed ratio. The animals ate less but used the macerated forage more efficiently for growth.

The nutrient utilisation by ruminants seems to be improved after maceration. This can be explained by the increased broken surface area which facilitates microbial colonization in the rumen. Hong et al. (1988b) used electron scanning microscopy to show that maceration actually separated lignified and unlignified cells, and damaged the external cuticular waxy layer. This can also explain why, in some instances, an apparently lower feed quality based on chemical composition might still result in equal or better animal performance compared to control forage. One example of such an apparent contradiction is the study by Hong et al. (1988a). They reported a lower CP and a higher NDF in macerated forage compared to the control, but the macerated alfalfa hay fed to sheep had 5% higher DMI and 25% higher average daily gain (ADG) than the conventional hay. Similarly, Suwarno et al. (1997) reported that beef cattle fed macerated round bale alfalfa silage (16.8% CP; 49.8% NDF) had 6% higher DMI and 11% higher ADG compared to beef fed non-macerated round bale silage with a nominally better feed value (18.1% CP; 48.2% NDF).

Maceration is also thought to increase the retention time of forage in the rumen because it is more compressible (Savoie et al., 1999c). A greater retention time should increase the overall digestion. Kraus et al. (1997) showed that ruminal digestion was faster during the first 24 h for macerated forage versus unmacerated forage, but the difference became smaller over a 48 h period. Hintz et al. (1999) suggested that high performance animals with rapid feed turnover rates would be expected to benefit most from maceration while animals at maintenance level will experience few if any nutritional benefit from maceration.

FUTURE PERSPECTIVES

Livestock producers. Maceration has two major advantages for livestock producers: reduction of the time required for field wilting of forage, thereby reducing the weathering risk, and improvement of the forage feed value. However, maceration may result in a lower quality feed if the forage is exposed to rainfall or conserved as very wet silage. Another disadvantage is the higher cost of a mower-macerator compared to a conventional mower-conditioner, because of the more complex mechanisms.

Rotz et al. (1990) carried out an economic analysis of maceration on dairy farms under the climatic conditions of Michigan. They hypothesized that a pull-type mower-macerator would cost $28,000 (U.S.) while a conventional mower-conditioner would cost $9,500 (U.S.). Considering the potential increase in feed value as a result of reduced field respiration and increased dry matter intake, they estimated that a dairy producer with 100 cows each averaging 8,000 kg of milk per year could have a net income increase between $10,000 and $15,000 because of substantially lower purchased feeds.

Another economic study carried out in the United Kingdom (McGechan et al., 1993) estimated an increase in net farm income for dairy producers converting to maceration technology. The gain was greater for farmers with a hay conservation system than for farmers with a silage conservation system. In Sweden, Thylen and Sundberg (1995) did a simulation study considering multiple year climatic conditions. They concluded that maceration would considerably reduce the risk of

weathering and generally improve the quality of conserved forages.

Alfalfa processors. The production of alfalfa cubes and pellets requires artificial drying which has been estimated to cost between $5 and $30 (U.S.) per ton depending on the price of natural gas and the moisture content of alfalfa delivered at the processing plant (Berney, 1990). Maceration can reduce the cost of artificial drying by reducing the moisture content of the harvested forage. Savoie et al. (1995) carried out a simulation study where they compared a self-propelled (SP) mower-macerator ($90,000 CDN) versus a conventional SP mower-conditioner ($60,000). Under a dry climate (20 to 30% daily rainfall probability), maceration was not beneficial. Under a wetter climate (40 to 50% chance of daily rainfall), maceration could increase the net income of the plant by $14,000 to $20,000 per mower typically used to harvest 5,000 t of crop per year (a net gain of $3 to $4/t).

Other studies have also looked at the effect of maceration on the feed value of cubes or pellets. Savoie et al. (1999b) observed that macerated alfalfa harvested in relatively dry field conditions (Falher, Alberta) produced pellets that had a greater ruminal degradability of DM (56.0% vs. 50.4%) than conventionally conditioned alfalfa. However, Savoie and Tremblay (1998) observed no difference in the ruminal degradability of alfalfa cubes that were either macerated or conventionally conditioned (59.4% vs. 60.2%, respectively) in a more humid climate (Louiseville, Québec).

Machinery manufacturers. A few commercial attempts to develop mower-macerators received some attention in Europe in the early 1990's (Deutz-Fahr, 1993; Krone, 1993). Some innovative conditioning devices, based on crushing, i.e. less intensive than maceration but more intensive than conventional roller conditioning, have been reported recently (Hill, 1997; McMorran, 1999). The partial list of patents related to intensive forage conditioning clearly indicate commercial interest in developing a more intensive conditioning system for forages.

Maceration has been shown to improve the field drying rate and the forage feed value for ruminants in several experiments. However, maceration has also been shown to cause more field losses and reduce forage quality if windrows are subjected to rain, humid conditions or excessive windrow handling. Forage maceration is a technology not suitable to all conditions. Commercial development, therefore, requires proper identification of customers most likely to gain from maceration.

CONCLUSIONS

1. Forage maceration has been the object of research at several sites around the world over the last twenty years. It has been shown to considerably improve the field drying rate and reduce respiration loss under ideal drying conditions. Various designs (peripheral rolls, staggered rolls, impact rolls) have been suggested to obtain an intensive mechanical conditioning.

2. Maceration can be implemented on various mowers (cutterbar, disk, pull-type, self-propelled). To maintain high mass-flow-rate at the time of mowing, maceration will require additional power. The estimated specific energy is in the order of 2 to 4 kW.h/t DM processed.

3. Maceration can improve the feed quality of forages by reducing the respiration rate and the proteolysis, especially under excellent drying conditions where the moisture content declines rapidly. Maceration can however reduce the feed quality of forages if it is followed by rain or humid conditions which will enhance respiration loss and protease activity.

4. Future development of intensive forage conditioning depends partly on further development of a mechanism that is simple enough to maintain low cost of fabrication and operation while still providing the effects of fast drying and improved feed value. Marketing development should seek the type of farming enterprise that will most benefit from maceration and be able to afford the higher machine cost associated with the adoption of the technology.

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Table 1. Effect of maceration on forage drying rate.

Type of macerator	Crop	Drying Time	Drying rate increase	Source
7-roll peripheral + press	Alfalfa	6 h	160%	Shinners et al. (1987)
5-roll peripheral, no press	Ryegrass	7 h	126%	Schurig and Rödel (1989)
8-roll staggered	Alfalfa	9 h	137%	Savoie
+ press	Timothy	9 h	61%	et al. (1993a)
2-roll staggered + press	Alfalfa	50 h	125%	May (1994)
6-roll peripheral, no press	Alfalfa	6 h	67%	Öztekin and Özkan (1997)
3-roll staggered + press	Alfalfa + Timothy	30 h	26%	Savoie et al. (1997)
3-roll staggered, no press	Alfalfa + Timothy	33 h	30%	Savoie et al. (1999a)
3-roll staggered,	Clover, early	34 h	65%	Descôteaux
no press	Clover, late	34 h	37%	and Savoie (1999)

Table 2. Specific energy required to operate the macerator.

Type of macerator	Specific energy (kWh/t DM)	Source
7-roll peripheral	9.2	Rotz et al. (1990)
3-roll crushing impact	2 to 4	Kraus et al. (1992)
8-roll staggered	3.8	Tremblay et al. (1994)
3-roll staggered, on disk mower	4	Savoie et al. (1997)
3 roll staggered-laboratory	3 to 4	Savoie and Tremblay (1997)
3-roll staggered on SP* mower	2 to 2.6	Savoie et al. (1999a)

* Self-propelled

Table 3. Forage fibre content after maceration and wilting.

Crop Species	Wilting Environment	Measured variable	Control	Macerated	Statistical significance
		Hong et al. (1988a)			
Alfalfa	Lab, 0 mm rain	NDF (%)	43.3	46.7	NR
Alfalfa	(on plastic)	ADF (%)	35.4	37.3	NR
		Rotz et al. (1991)			
Alfalfa	Lab, 0 mm rain	NDF (%)	43.1	46.2	$P< .01$
Alfalfa	Lab, 18 mm rain	NDF (%)	44.6	54.2	$P< .01$
Alfalfa	Lab, 62 mm rain	NDF (%)	45.6	60.2	$P< .01$
		Savoie et al. (1993b)			
Alfalfa	Lab, 0 mm rain	ADF (%)	29.6	27.6	NR
Alfalfa	Lab, 6 mm rain	ADF (%)	30.0	32.5	NR
Timothy	Lab, 0 mm rain	ADF (%)	32.9	32.3	NR
Timothy	Lab, 6 mm rain	ADF (%)	34.9	35.3	NR
		Petit et al. (1994)			
Timothy	Field, 0 mm rain	ADF (%)	39.2	45.5	$P< .05$
Alfalfa	Field, 0 mm rain	ADF (%)	43.3	52.6	$P< .05$
		Agbossamey et al. (1998)			
Timothy	Lab, 0 mm rain	ADF (%)	34.3	33.9	NS
Alfalfa	Lab, 0 mm rain	ADF (%)	38.5	38.3	NS
Alfalfa	Field, 3.2 mm rain	ADF (%)	41.4	44.1	$P< .001$
		Suwarno et al. (1999)			
Alfalfa	Field, 0 mm rain	NDF (%)	34.7	37.4	$P< .05$
Alfalfa	Field, 20 mm rain	NDF (%)	33.0	40.9	$P< .05$
		Charmley et al. (1999)			
OG + WC	Field, 1 mm rain	NDF (%)	49.2	51.0	NR
OG + WC	Field, 1 mm rain	ADF (%)	32.4	36.0	NR

Abbreviations: NDF = neutral detergent fibre; ADF = acid detergent fibre; OG = orchardgrass, WC= white clover; Lab = laboratory environment; NR = not reported; NS = not significant.

Table 4. Effect of forage maceration on animal performance.

Crop[a] species	Animal species	Measured[b] variable	Control	Macerated	Statistical[c] significance
		Hong et al. (1988a), 60% Hay + 40% Grain			
Alfalfa	Dairy goats	DMI (kg/d)	2.44	2.58	$P < .01$
Alfalfa	Dairy goats	4% FCM	3.3	3.7	$P < .01$
		Koegel et al. (1992a), 65% Chopped silage, 35% Grain			
Alfalfa	Dairy cows	Milk (kg/d)	24.5	24.2	NS
Alfalfa	Dairy cows	ADG (kg/d)	.08	.44	$P < .01$
Alfalfa	Dairy cows	MEF (MJ/kg)	4.61	5.11	NS
		Savoie and Block (1994), Hay and 10 kg/d of grain			
Alfalfa	Dairy cows	Milk (kg/d)	29.9	34.3	$P < .05$
Alfalfa	Dairy cows	Hay DMI (kg/d)	14.0	16.1	$P < .05$
		Chiquette et al. (1994), 100% mature hay			
Timothy	Steers	DMI (kg/d)	10.5	10.3	NS
Timothy	Steers	DMD (%)	66.5	65.7	$P < .05$
Timothy	Steers	EDDM (%)	36.0	39.9	$P < .05$
		Petit et al. (1994), 100% Hay			
Alfalfa	Sheep	DMI (g/d)	899	971	$P = .09$
+ Timothy	Sheep	DMD (%)	53.0	57.9	$P = .006$
		Frost et al. (1995), 100% Chopped silage			
Ryegrass	Sheep	DMI (g/d)	830	780	NS
Ryegrass	Sheep	DMD (%)	68.7	69.0	NS
		Suwarno et al. (1997), 100% Round bale silage			
Alfalfa	Beef	DMI (%BW)	2.77	2.91	$P = .04$
Alfalfa	Beef	ADG (kg/d)	0.9	1.0	$P = .04$
		Petit et al. (1997), 72% Hay, 28% Grain			
Timothy	Sheep	DMI (%BW)	3.98	3.80	$P = .04$
Timothy	Sheep	ADG (g/d)	279	285	NS
Timothy	Sheep	GFR	0.217	0.235	NS
		Charmley et al. (1999), 100% Round bale silage			
OG + WC	Beef	DMI (%BW)	2.73	2.71	NS
OG + WC	Beef	ADG (kg/d)	0.87	1.09	$P < .01$
OG + WC	Beef	GFR	0.103	0.130	$P < .001$
		Charmley et al. (1999), 100% chopped silage			
OG + WC	Beef	DMI (%BW)	2.15	1.76	$P < .05$
OG + WC	Beef	ADG (kg/d)	1.00	1.03	NS
OG + WC	Beef	GFR	0.148	0.184	$P < .001$
		Agbossamey et al. (2000), 100% chopped silage			
Alfalfa	Sheep	DMI (%BW)	2.31	2.88	Q
Alfalfa	Sheep	DMD (%)	60.8	60.1	L, Q

[a]OG = orchardgrass; WC = white clover.

[b]DMI = dry matter intake; FCM = fat corrected milk; ADG = average daily gain; MEF = metabolizable energy of forage; DMD = dry matter digestibility; EDDM = effective degradability of dry matter; GFR = Gain:feed ratio.

[c]NS = non significant; L and Q= linear and quadratic effects of maceration.

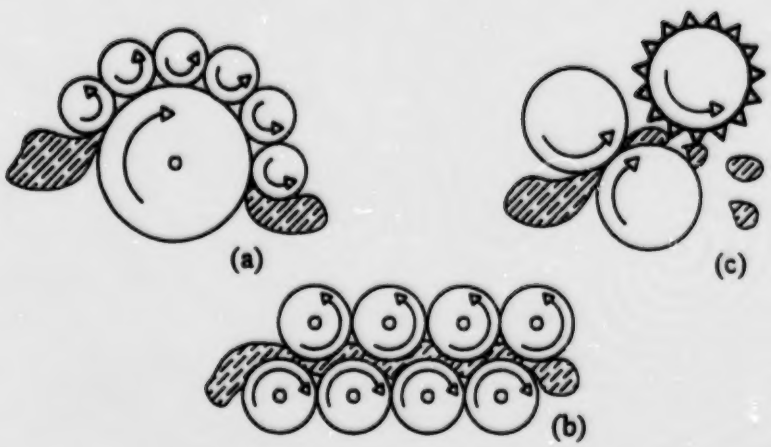

Figure 1. Three configurations for intensive forage conditioning: (a) peripheral roll macerator; (b) staggered roll macerator; (c) crushing-impact macerator.

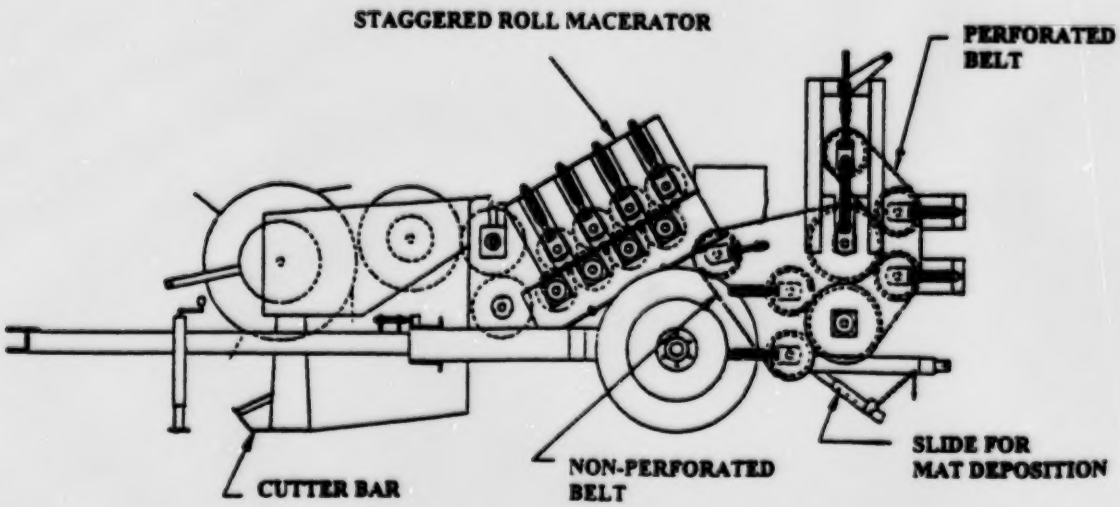

Figure 2. Experimental field prototype with cutter bar mower, eight staggered rolls and belt press (Savoie et al., 1993a).

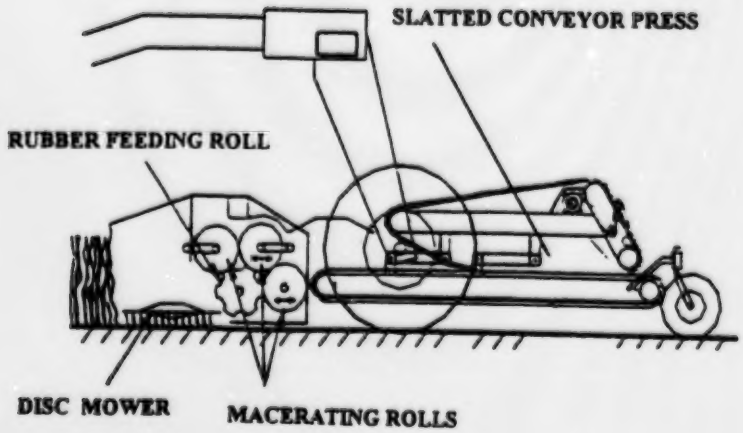

Figure 3. Experimental field prototype with disc mower, from staggered rolls and slatted conveyor press (Savoie et al., 1997).

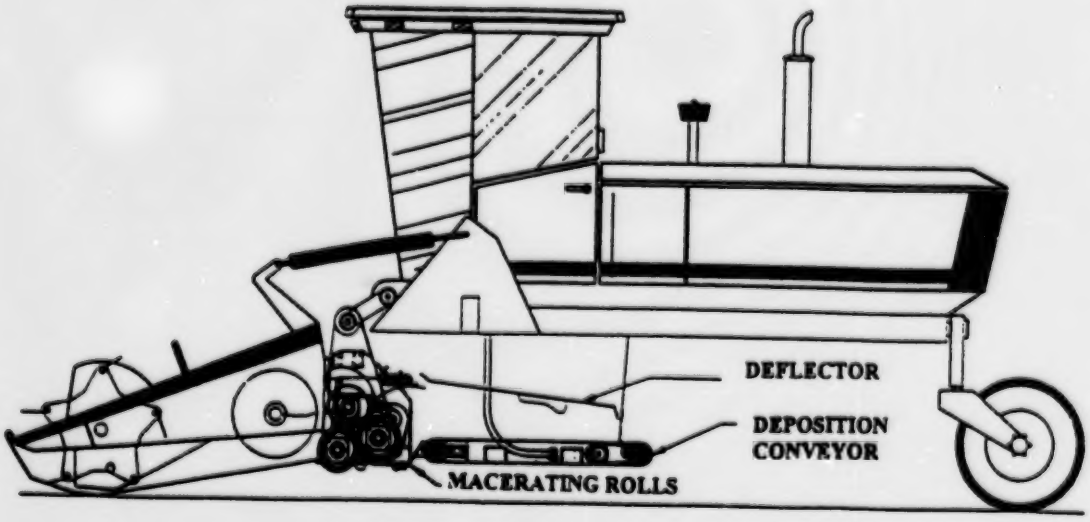

Figure 4. Three-roll staggered macerator adapted to a self-propelled mower (Savoie et al., 1999a).

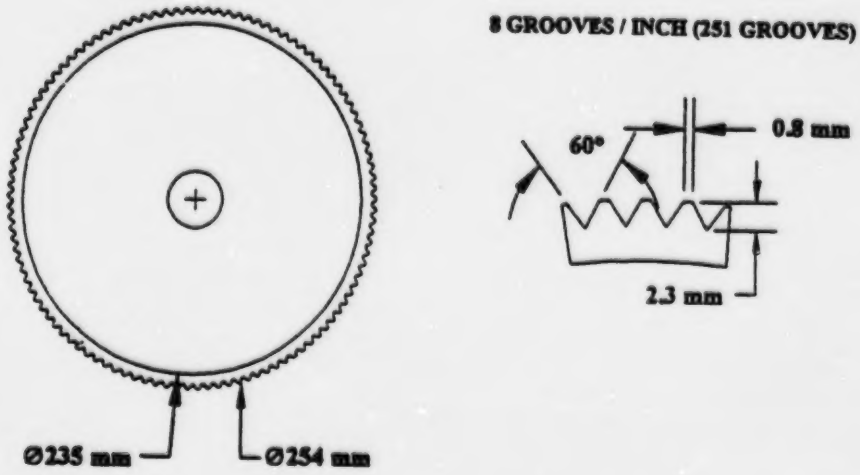

Figure 5. Side view of a macerator roll.

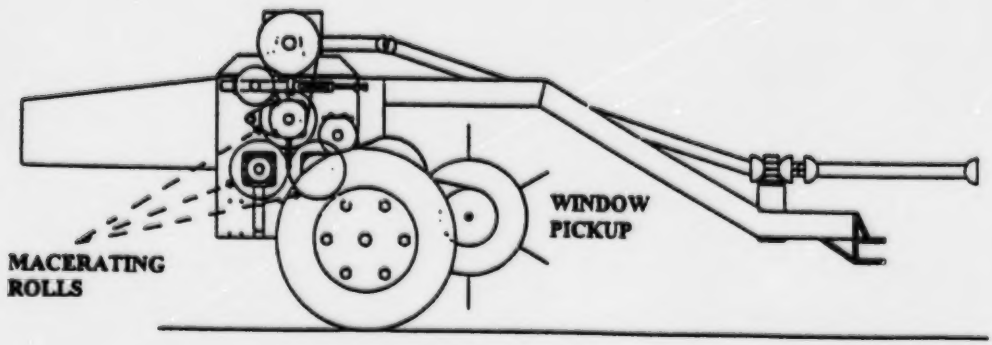

Figure 6. Three-roll staggered macerator operated with a window pickup (Descôteaux and Savoie, 1999).

PROTEIN SOLUBILITY IN PROCESSED ALFALFA CHOPS AND GROUND MEAL

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ABSTRACT

Alfalfa protein is susceptible to post-harvest operational conditions, undergoing nutritional and functional changes during processing. In this study protein solubility of processed ground and chopped alfalfa was examined by determining the acid detergent insoluble nitrogen (ADIN) content of ground re-welted alfalfa were treated with high temperature (700°C), low temperature (100°C), steam, and microwave. In a second study, stems and leaves of chopped alfalfa were exposed separately to drying temperature ranging from 80 to 800°C. It was found that all modes of heat treatments resulted in reduced protein solubility. Temperature of the treatment was more important than the treatment time. Commercial dehydration was found to cause far more severe reduction in protein solubility than experimental treatments in the laboratory. The protein solubility of chopped alfalfa was lowered during drying above 100°C. However the most damage to the protein was found at a temperature of 150°C for 7.5 minutes exposure for stems and 200°C for 1.25 minutes exposure for leaves.

INTRODUCTION

Processing of green alfalfa can involve drying, size reduction, steam conditioning, pelleting, cubing, and baling. These processes are carried out at various thermal and moisture conditions. For example, during drying heat is supplied to fresh or partially sun dried alfalfa at temperatures ranging from 200 to 800°C (Wood and Sokhansanj, 1990). The particles of alfalfa may experience high temperatures but for a short time. During the heat treatment the moisture content of particles drops from 80% to less than 8%. In pelleting, ground alfalfa is mixed with super heated steam and dry heat prior to compression in the pellet mill. Similarly, in the cubing process, heat and moisture are added to alfalfa chops to make it more pliable for the subsequent cubing. Interaction of processing parameters, such as temperature and moisture level, with the nutritive constituents of alfalfa is inevitable. Protein is a major constituent of alfalfa which is vulnerable to processing conditions and that may undergo considerable change.

Church (1991) states that for fast growing and high producing ruminants, rumen microbial N-supply is insufficient to meet requirements. The required additional protein should by-pass microbial fermentation in the rumen and be available in the lower gastro-intestinal (GI) tract to be utilized. This excess protein is called rumen "escape protein." The solubility of various N fractions is an important factor in determining the suitability of protein for digestion in the rumen or the GI tract. Generally it is accepted that less soluble protein is more likely to escape the microbial fermentation in the rumen.

Table 1. Total nitrogen N and ADIN in the original forage - Trial 1.

	N (% DM)	ADIN (% DM)	
		Average	std dev. (%)
Leaves (n=6)	4.76	0.31	0.03
Stems (n=7)	1.76	0.21	0.02
Fine stem (n=2)	2.79	0.20	
Chops (n=2)	3.40	0.27	

Alfalfa contains 17-25% crude protein on a dry matter basis which varies depending on environmental conditions, maturity stage and management factors (Walton, 1983). The solubility of protein in forages is generally greatest in lush, young plants and decreases with age (Church, 1991). Temperature is the most prominent factor to cause changes to protein solubility during alfalfa processing. Van Soest (1965) found that the concentration of N insoluble in acid detergent solution (ADIN) increased in forages when they were heated. As the temperature is increased, the protein molecules adhere to the fibers in alfalfa and become insoluble suggesting the formation of acid stable linkages between N compounds and other forage constituents. Thus, ADIN in forages is symbolic of the amount of indigestible or poorly digested protein that results from excessive heat during processing or exists naturally in forages even before processing. Martens (1976) had shown that ADIN also exists in forages that have not been heated and related them to a strong bond between lignin and a fraction of protein.

The objectives of this study were to examine the effect of various conditions on protein solubility and availability as reflected by percent ADIN (acid detergent insoluble nitrogen) (Trial 1) or protein solubility (Trial 2). Two series of tests were conducted. The first series of tests were conducted by Patil (1994) when he studied in detail the drying characteristics of chopped alfalfa including stem and leaf fractions. The second series of tests were performed by Yang (1998) on ground alfalfa.

TESTS ON ALFALFA CHOPS

Materials and Methods

Fresh alfalfa at 10% bloom was used. The alfalfa was brought to the laboratory in a double layered black polyethylene bag and was stored in freezer at -20°C. Before exposing to thin layer drying alfalfa was thawed completely. The leaves and stems were separated manually. The stems were

chopped into 5 cm lengths. Two thin layer dryer setups were constructed. An electrically-heated dryer was used up to temperatures of 250°C. The propane-heated dryer was used above 250 to 800°C. Two grids each consisting of three thermocouples measured the air temperature before and after the drying tray. The moisture losses were monitored over time by manually weighing the samples intermittently to calculate the instantaneous moisture content.

Table 2. Minimum and maximum duration (seconds) during which the leaves and stems were exposed to drying temperatures - Trial 1

	Drying temperature (°C)								
	80	100	150	200	250	300	400	600	800
Stems	720	300	120	60	45	15	15	10	5
	3600	1500	450	210	180	90	60	40	20
Leaves	270	90	60	30	25	15	15	10	5
	1500	540	270	105	90	60	20	20	15

Samples were collected after different exposure times and ADIN% was determined. The original crude protein content for chop, stem, fine stem and leaves was determined (AOAC, 1990).

Further experiments on change in ADIN% were conducted only on major components such as stems and leaves. The ADIN% was determined by NFTA Method 6 (NFTA, 1993). A sub-sample of the ADF residue was analyzed for nitrogen to determine the nitrogen content of the ADF.

Results

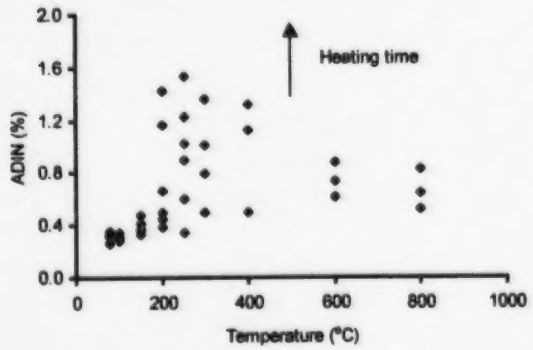

Figure 1. ADIN concentrations of alfalfa stems exposed to increasing temperatures and time.

The original levels of N and %ADIN in leaves and stems are given in Table 1. Data show that leaves contained three times more N than the stems. The nitrogen content of fine stems was higher than the nitrogen content of the coarser stems. Table 2 lists the drying temperatures, minimum and maximum exposure times for alfalfa leaves and stems. The maximum times were recorded when the material began scorching. This is important as Table 2 shows at the lower temperatures the particles could be exposed to heat for longer time than at high temperatures. Leaves were particularly susceptible to burning so they were exposed to high temperatures for only a few seconds.

With the exposure of alfalfa to higher temperatures during drying, the protein solubility decreases for both stems and leaves. The data on the %ADIN values at different exposure times and temperatures for leaves and stems are given in Figures 1 and 2. The estimated protein contents indicated that in both stem and leaves the damage to the protein did not take place up to 150°C for leaves and 100°C for stems. The protein solubility was found to reduce considerably when the leaf sample was exposed to 200°C for more than 75 s. In the case of stems the protein solubility showed a reduction when exposed at 150°C for 300 s. The largest reduction in protein solubility was for stems at 150°C for 450 s (7.5 min) exposure and for leaves to 200°C for 105 s (1.75 min.)

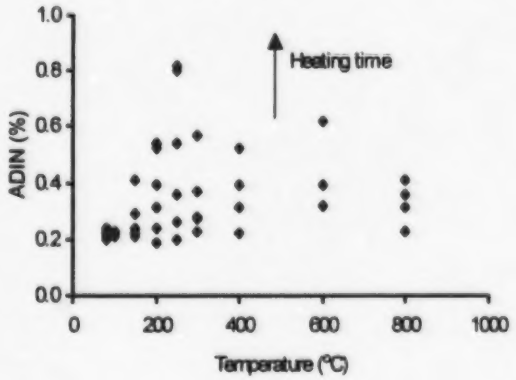

Figure 2. The level of ADIN percentage of alfalfa leaves exposed to increasing temperatures and time.

The mathematical relationship to predict the %ADIN at any time t is useful to predict %ADIN values in the process. The ADIN % was found to increase exponentially with drying time hence it was modeled as a kinetic reaction of the nth order.

$$\frac{ADIN_f - ADIN_t}{ADIN_f - ADIN_o} = \exp(-kt^n) \qquad 1$$

where subscripts f, t and o correspond to the value of %ADIN at the end of drying, at any time t and before drying. In this equation, k is the reaction constant which is dependent on the drying air temperature and n is the reaction order. In the case of stems, both the constants n and k were found to be dependent upon drying air temperature as per the Arrhenius equation. The equations were:

$$n = 0.98\exp(\frac{757.57}{T_K}) \qquad (R^2=0.80) \qquad 2$$

$$k = 184056\exp(\frac{-8273.7}{T_K}) \qquad (R^2=0.93) \qquad 3$$

where T_K is absolute temperature in K and time t is in min.

Similarly for the leaves the non linear relationship was observed up to 250°C. The %ADIN change was found to be linear with exposure times at temperature above 300°C.

The mathematical relationship of constants for leaves with drying air temperatures were:
For 150°<T<250°C

$$k = \exp(-2.90 + \frac{0.93}{T_K}) \qquad (R^2=0.97) \qquad 4$$

$$n = -372.48 + \frac{3.5766 \times 10^5}{T_k} - \frac{8.43 \times 10^7}{T_k^2} \qquad (R^2=1) \qquad 5$$

For 300° <T<800°C a linear equation fit the data better:

$$\frac{ADIN_f - ADIN_t}{ADIN_f - ADIN_o} = A + Bt$$

where

$$A = 0.26088 - \frac{9.723 \times 10^{-3}}{T_k} + \frac{6.445 \times 10^{-3}}{T_k^2} \qquad (R^2=0.87) \qquad 6$$

$$B = \exp(-9.60 \times 10^{-2} + \frac{0.21}{T_k}) \qquad (R^2=0.95) \qquad 7$$

TESTS ON ALFALFA GRIND

Materials and Methods

Fresh alfalfa at three stages of maturity (pre-bloom, 5% bloom, and 100% bloom) was collected separately from Agriculture and Agri-Food Canada research farm near Saskatoon. The first and second maturity stages were from second cut alfalfa, and the over-mature alfalfa was from unattended first cut. In addition, a commercially dehydrated and ground alfalfa meal at 4% moisture was also sampled from an alfalfa processing plant and used in this study.

The fresh alfalfa plants were chopped into 25 mm pieces with an electric trimmer before they were spread out on a polyethylene sheet in a thin layer for drying at the ambient temperature of 22°C in the shade. To accelerate the moisture removal, air was blown over the surface of the sample with a domestic fan. The moisture content of the samples was reduced to about 10% before they were ground in a hammer mill. The screen size was 1.5 mm. After grinding, alfalfa meals were blended in a cement mixer to ensure homogeneity of stem and leaf mixture. The ground samples were then exposed to the experimental heat treatments.

High temperature treatment: A high temperature propane drier/heater (the same used for drying chopped alfalfa) was used to test the effect of heat (700°C) for 10, 35, 50 and 70 seconds on the 5% bloom samples only.

Low temperature heating: In a forced ventilation oven at 103°C for 24 hr alfalfa samples at all three stages of maturity were subjected to low temperature in duplicate to determine the effects on protein solubility and ADIN concentration.

Steam heating: Saturated steam is used commercial to condition alfalfa meal prior to pelleting. The heating time was set at 0, 30, 60, 120, 240, 360 and 480 seconds.

Microwave heating: Twenty five grams of sample was filled into a glass test tube subjected to microwave irradiation at the power level of 800 W for 10, 30, 60, 90 and 120 seconds. This experiment was conducted in duplicate for all three maturity stages.

Analytical methods: Crude protein was determined using the copper catalyst Kjeldahl method (AOAC, 1990). Protein solubility was determined following the Borate-Phosphate buffer method (Roe et al. 1990). Acid detergent insoluble nitrogen (ADIN) was determined using Method 6 by Undersander et al. (1993) and AOAC 930.15 (AOAC, 1990) method was used to determine the moisture content of ground alfalfa samples.

RESULTS

Table 3 lists percentages of moisture content (MC) crude protein (CP), ADF and NDF ADIN% and protein solubility (PS) for all samples before treatments. Except for moisture content, the rest of data are on a percent dry matter basis. Crude protein decreased with maturity from 32.9% for young plant to 19.7% for the over-mature plant.The crude protein of the commercial grind was in the range of the over-mature plant. Some variations in crude protein was as follows 32.88± 1.06, 24.50± 1.18

Table 3. Analysis of ground alfalfa samples (before treatment) and from a commercial plant

Sample	Condition	MC[1]	CP[2]	ADF[1]	NDF[1]	ADIN[3]	PS[1]
A	Young plant<30 cm	87.6	32.9	22.2	25.7	0.22	59.8
B	5% bloom	79.5	24.5	32.7	39.6	0.24	60.2
C	Over-mature	78.3	19.7	37.7	46.6	0.20	60.8
D	Commercial grind	5.3	18.2	37.0	48.1	0.43	24.7

[1]Mean of duplicates. The percent difference <0.1 for m.c., <3.4 for ADF, <1.9 for NDF, and < 2.8 for PS.

[2] Mean of six replicates. Standard deviation ranged from 0.4 to 1.1

[3] Mean of four replicates. Standard deviation ranged from 0.0062 to 0.0137

and 19.68± 0.16 for "Young", "5% Bloom" and "Over-mature" samples, respectively (n=6). The fiber content of the samples increased with maturity. The commercial grind sample showed a marked decrease in fiber indicating loss of the lesser cellulosic part of the plant. It was noted that the protein solubility and ADIN level were in the neighborhood of 60% and 0.20%, respectively, with slight variation for different maturity stages. The increase percent ADIN and the corresponding decrease in protein solubility in commercial grind sample indicates the effect of heat during dehydration.

High temperature treatment: Figure 3 shows the relationship between protein solubility and the heating time during heating with propane heater. It can be seen that protein solubility decreased from 60.2% at time zero (the value for "5% bloom" alfalfa) to 44.5% after 70 s, approximately in a linear pattern:

$$Y = 58.4227 - 0.1956x \qquad (R^2=0.93) \qquad 8$$

This relationship resembled those of other biomaterials under dry heat conditions, such as peanuts (Neucere and Cherry, 1982). This was because high temperature propane heat was similar to dry heat. The protein solubility of commercially dehydrated alfalfa meal sampled from a dehy plant was 24.7%. This value was much lower than that of control samples and also lower than that of the alfalfa sample heated at 700°C for 70 seconds. This was probably because the inlet temperature of commercial drum drier plant is higher than 700°C and alfalfa is exposed more than 3 min for drying. The much lowered protein solubility of dehydrated alfalfa signified that a high proportion of the protein would escape degredation in the rumen.

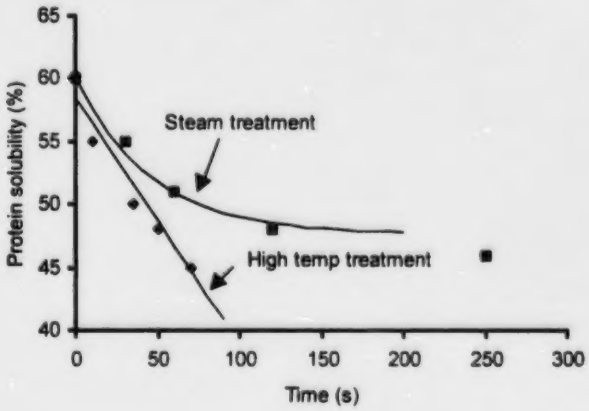

Figure 3. Effect of steam treatment and high temperature treatment on protein solubility in alfalfa grind.

The ADIN contents of the "5% bloom" alfalfa samples heated at 700°C for 60 , 70 and 85 s, respectively, were 0.35 , 0.39 and 0.91%. In the case of 70-s heating at 700 °C, the sample was slightly burned. The ADIN content was high for the case of 85-s heating, because the sample was severely burned.

Low temperature treatment: As compared to control, the protein solubility was about 7, 10 and 15% for "5% Bloom", "Over-mature" and "Young" alfalfa, respectively. The protein solubility for "Young" alfalfa reduced the most among all, more than double the reduction percentage of "5% Bloom" alfalfa. For "5% Bloom" alfalfa, the level of protein solubility after heating was comparable with that heated at 700°C for about 13 seconds as predicted by the regression equation. The

reduction in protein solubility caused by low temperature heating was generally less severe than that by high temperature heating. It was also found that the reduction in the protein solubility during commercial dehydration was far more severe than that of low temperature heating. This seemed to suggest that protein solubility depended more on the temperature than the length of heating time.

Steam heating: The relationship between protein solubility and the heating time for steam treatment is shown in Figure 3. Unlike the linear descending trend in high temperature heating, protein solubility in this case declined quickly from 59.8 to 48.3% within 120 s before it fluctuated within 47-48% range afterwards. This might be explained by: 1) reduced steam temperature when it was released from the high pressure pipe line to an atmospheric chamber, and 2) the temperature of the materials heated with steam could only rise as high as the temperature of steam at atmospheric pressure. One pertinent observation was the pattern of meal temperature monitored during steam treatment. In the cases of 240, 360 and 480 s treatment, the meal temperature after 100 s was around 112°C and increased no further. This result also suggested that protein solubility had more to do with temperature than the length of heating. As a moist heat case, steam treatment brought more reduction to alfalfa protein solubility than did other treatments under the conditions tested.

A non-linear exponential model as shown in Figure 3 was found to closely approximate the relationship between protein solubility (%) and steam treatment time x in s:

$$Y = 47.6867 + 12.3738 \exp(-\frac{x}{44.564}) \qquad (R^2=0.903) \qquad 9$$

Microwave heating: Figure 4 shows protein solubility in relation to microwave heating time at the power level of 800 W for young, 5% bloom, and Over-mature alfalfa. At time zero, protein solubility of alfalfa at three maturity stages were in the vicinity of 60%. As heating time increased, protein solubility decreased more or less in an exponential pattern. The margin of decrease was different for three samples at different maturity stages. For 5% bloom and over-mature alfalfa, protein solubility decreased non-linearly until at the heating time of 60 s when it started levelling off. However, microwave heating caused the most severe reduction in protein solubility of young plants. This is evident from Figure 4 at the heating time of 30, 60 and 120 s where the mean protein solubility of young alfalfa were the lowest of all.

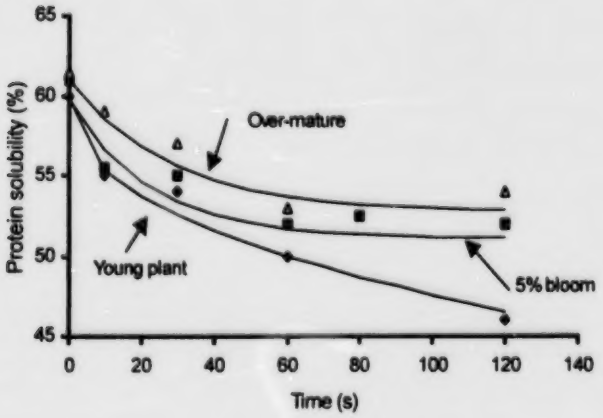

Figure 4. Protein solubility of grind samples exposed to microwave heating.

To approximate the relationship between protein solubility of alfalfa and microwave heating time at 800 W power level, the pooled data on protein solubility of alfalfa samples at three maturity stages were fitted to exponential, logarithmic and polynomial equations. It was found that the polynomial expressions as given in Figure 4 were the best in terms of the coefficient of determination:

Young plant

$$Y = 59.8074 - 1.6718x^{0.4326} \qquad (R^2=0.99) \qquad 10$$

5% bloom

$$Y = 51.1108 = 8.5976\exp(-\frac{x}{22.4204}) \qquad (R^2=0.95) \qquad 11$$

Over-mature

$$Y = 52.7504 + 82172\exp(-\frac{x}{28.0978}) \qquad (R^2=0.94) \qquad 12$$

It was also evident from Figure 4 that the polynomial fit curve most closely represent the curve of the protein solubility versus microwave heating time for "5% bloom" alfalfa.

CONCLUSION

Based on this study, the following conclusions can be drawn:

1. The protein solubility and the ADIN of unprocessed alfalfa were in the neighbourhood of 60% and 0.20% irrespective of maturity stages. The commercially dehydrated ground sample showed a marked decrease in protein solubility.
2. The protein solubility of alfalfa decreased with the heating time. The decline generally followed an exponential trend for both ground and chopped alfalfa.

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FUNGAL GROWTH ASSESSED ON DETACHED STEMS OF GRASS AND LEGUME FORAGE SPECIES

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ABSTRACT

Spoilage of harvested forage may occur under conditions favourable to mould growth. To compare plant material of different kinds and environments for their capacity to support fungal growth after harvest, a technique was evolved using pieces of stems incubated in seed germination pouches. Pieces 135 mm in length were cut from plants grown in the glasshouse or in the field and they were sterilized in the autoclave. For assessing the growth of fungi, detached stems were spaced vertically in seed germination pouches, at the rate of four stems per pouch. The tip of each stem was inoculated with a 5-mm plug taken from an actively growing colony of one of the four moulds tested. The blotter paper inside the pouches was kept wet throughout the 10-day incubation period, in the dark. Stems were examined at different intervals and the advance of fungal growth along the stem was measured on each one. The fungi tested grew at different speeds and they were significantly different overall in the following order: *Penicillium citrinum* > *Aspergillus niger* > *Penicillium roquefortii* > *Fusarium avenaceum*. The fungal growth also varied with the forage species tested. Grasses were more susceptible than legumes in average with the exception of red clover which supported fungal growth equivalent to grasses. Smooth brome was found to favour fungal growth the most and white clover the least. Stolons of white clover were much more susceptible to fungal colonization than stems. Field grown plants of red clover gave results similar to glasshouse grown plants. There were significant plant-fungi interactions.

TOWARDS IMPROVED SILAGE QUALITY – A REVIEW

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Abbreviations: ADF, acid detergent fibre; **CP**, crude protein; **DM**, dry matter; **NDF**, neutral detergent fibre; **NE**, net energy; **TDN**, total digestible nutrients; **UIP**, undegraded intake protein; **VFA**, volatile fatty acids

ABSTRACT

Silage quality, as with all forages, is governed by the maturity of the crop at harvest. However, fermentation in the silo further influences nutritive value of silage by reducing voluntary intake and utilization of digestible nutrients. Silage research up to the present time has focussed on closing the gap between feeding value of the original crop and that of the resulting silage. This review focusses on the advances made towards closing that gap and explores the possibility that in the future ensiling can become a tool for actually increasing the feeding value of forages. The relationship between silage fermentation quality and nutritive value will be examined, with emphasis placed on measures to minimize the negative effects of fermentation on animal production. Recent literature is reviewed which suggests that many factors previously thought to reduce silage intake, such as pH, lactic acid and dry matter, have, in fact, only a casual relationship with intake. Concentrations of fermentation acids do not seem closely related to silage intake, however they are critical in determining the balance of VFA produced in the rumen. This in turn, affects the non-glucogenic ratio and can influence milk and body composition in productive livestock. While rumen ammonia is often implicated in reducing silage intake, protein solubility may be more the causal agent than ammonia per se. Protein solubility is also a major factor in reducing the efficiency of silage protein utilization. Methods to reduce protein solubility in silages are discussed. Methods shown to improve silage feeding value include effective wilting and rapid acidification, either by direct acidification or use of inoculants. Their widespread adoption has undoubtedly contributed to improvements in animal production from silages in recent years.

Key words: Silage, Feeding value, Voluntary food intake, Fermentation, Ruminant

INTRODUCTION

In most ruminant production systems, livestock derive between 40 and 90% of their feed requirements from forages. In Canada, where the winter feeding period can last for 7 mo or longer, successful forage conservation is crucial to production. Haymaking and ensiling are the only options

available to farmers wanting to conserve forage on a large scale. In drier climates, haymaking is still important. However, there has been a trend over the last 30 yr or so for the proportion of forage conserved as silage to increase, while the proportion dedicated to hay has declined (Wilkinson et al. 1996).

Ensiling offers many advantages over haymaking. Large quantities of forage can be conserved in a short time, forage conservation is less weather dependent and thirdly, silage is well suited to mechanization. However, a major disadvantage associated with silage making is that the feeding value of the resultant forage is reduced relative to that of the original crop.

Silage research up to the present time has focussed on closing the gap between feeding value of the original crop and that of the resulting silage. Feeding value, in this case, is defined as the product of the nutritive value and potential voluntary intake of the forage (Wheeler and Corbett, 1989). This review will focus on the advances made towards closing that gap and explore the possibility that in the future ensiling can become a tool for actually increasing the feeding value of forages. The relationship between silage fermentation quality and nutritive value will be examined, with emphasis placed on measures to minimize the negative effects of fermentation on animal production.

DEFINING SILAGE QUALITY

For farmers, quality (or feeding value) in silage is frequently measured by a simple index, such as CP or TDN. Unfortunately, these indices only reflect the growth stage at harvest and do not characterize silage fermentation. While feeding value of silage is primarily determined by digestibility, it is nonetheless influenced by silage fermentation (Steen et al, 1998). Thus, an accurate assessment of silage quality should include a comprehensive range of chemical analyses. Cost and time preclude many of these analyses on a routine basis, however, new methodologies are being developed to circumvent the need for complex analyses and yet still provide an all-encompassing measure of feeding value (intake potential, digestibility, fermentation profile). These include near infra red spectroscopy (Steen et a l. 1995; Offer et al. 1998) and electromeric titration (Moisio and Heikonen, 1989; Offer et al. 1998) both of which are widely used in Europe. Their adoption has been slow in North America for two main reasons. Firstly, in North America, we are faced with a large geographical area, with diverse climatic and weather conditions, throughout which is grown a wide range of crop species. This diversification makes such methods, based on indirect relationships between feeding value and crop characteristics unsuitable. Added to this, the North American climate is better suited to wilting than that of Europe, and in general, silage fermentation has less negative effects on silage feeding value than in Europe. Nevertheless, ensiling does modify feeding value, and today North American farmers are perhaps worse off than their European counterparts, because this facet of feeding value has, in large part, been ignored.

Table 1 categorizes some parameters of silage quality. Routine analysis almost exclusively concentrates on factors related to the crop, and in particular crop maturity. Indices of silage fermentation are seldom accounted for in Canada. Furthermore, some routinely reported indices of

silage quality (e.g. NE, TDN) are derived from ADF or NDF concentration and not measured directly. Generally, producers get a reasonable assessment of crop maturity (digestibility) but a poor assessment of silage fermentation.

Today, various ensiling techniques have evolved best suited to the size and profitability of the ruminant enterprise and the prevailing climate. Thus, round bale, bunker, bagged, heap and tower silages all have a place. Silage dry matter concentration can range from 20% up to 80%. Crops for ensiling range from vegetable by-products through cereals to grasses and legumes, all of which can be ensiled without or with one of several additive types. Given this diversity, it is inevitable that in many cases silage fermentation quality is critical. This becomes even more the case as ruminant rationing is refined to exactly tailor the supply of nutrients to the requirements of the animal (NRC 1989; AFRC 1993; NRC 1996).

THE INFLUENCE OF SILAGE FERMENTATION ON DM INTAKE

It is generally recognized that voluntary intake of silage is less than that of the same forage that has not undergone fermentation. This is well exemplified in Figure 1 where the intake of silage by dairy cows declines as the concentrations of silage ammonia and butyric acid increase (Cushnahan et al. 1995). These authors achieved this relationship by ensiling the same forage for varying lengths of time (0, 21 or 63 days) before feeding to cows. Mayne and Cushnahan (1994/95) reviewed all available literature and showed that, on average, silage intake was 27% less than intake of the same forage fed without ensiling. Today, however, we should question the validity of this conclusion. Figure 2 shows that the reduction in forage intake due to ensiling has steadily declined over the last 40 years and recent research would suggest that ensiling has relatively little impact on voluntary intake (Cushnahan and Mayne, 1995; Keady and Murphy, 1998). Many of the comparisons reviewed in early years were done before the widespread use of effective additives and were made on wet silages.

Fermentation acids and silage intake

Butyric acid was first implicated as being responsible for reducing silage intake in 1963 (Harris and Raymond 1963). Since then other volatile fatty acids (VFA) have been identified (Brown and Radcliffe 1971; Wilkins et al. 1971; Wilkins et al. 1978) as well as lactic acid (Choung and Chamberlain 1993b).

However, the role of lactic acid and VFA other than butyric acid in reducing silage intake still remains controversial. Buchanan-Smith and Phillip (1986) infused various silage fermentation products directly into the rumen and monitored intake of a standard silage. Results were ambiguous, however, it was apparent that many silage fermentation end-products were unimportant. In a subsequent study, Buchanan-Smith (1990) assessed the effect of adding individual or combinations of VFA and ammonia on silage palatability by measuring intake for 30 min after a meal. Once again, the results were equivocal. While acetic acid did reduce intake when supplemented alone, other

VFA, lactic acid and ammonia had no consistent effects. A creative approach to assessing the importance of fermentation acids on silage DM intake was adopted by Dawson and Mayne (1998). These authors squeezed juices from two silages of diverse fermentation quality and recombined these juices with the alternate silages. No relationship was found between organic acid concentration and silage DM intake.

Recently, large numbers of research trials have been re-analysed in an attempt to predict voluntary intake from silage fermentation characteristics (Rook and Gill 1990; Rook et al. 1990; Steen et al. 1995; Steen et al. 1998; Wright et al. 2000). These studies found only moderate correlation between fermentation acids and voluntary intake.

Silage pH and silage intake

Low pH in silages is often associated with poor intakes because low pH in the rumen reduces cellulolytic activity and depresses intake. However, there is no relationship between silage pH and rumen pH (Rooke, 1995). Silage is neutralized by saliva upon consumption. Low rumen pH is typically associated with grain-based not forage-based diets. In studies where silage intake has been increased with neutralization (McLeod et al. 1970), more recent research suggests that this is due to increased rate of passage in response to the bicarbonate (Newbold et al. 1991). Rooke (1995) and Offer (1997) have postulated that the free acid content of silage, as distinct from pH, is related to intake. However, Rooke (1995) also suggests that lactic acid may have a direct effect on palatibility, since sour taste is associated with reduced palatibility. Any direct effects of lactic acid on silage DM intake may be more important in the short term than the long term and related to a negative feedback (Offer 1997).

Ammonia N and silage intake

Ammonia N has long been associated with reduced silage intake. In part this has arisen because it can be readily measured, and may act as a simple index of silage fermentation quality. Clostridia decarboxylate and deaminate amino acids releasing ammonia. Many of the other products of amino acid breakdown can reduce intake (Barry et al. 1978; Buchanan-Smith 1990). Thus, silage ammonia concentration itself may not be important. Nevertheless, in recent papers comparing silages of differing fermentation characteristics, ammonia still ranks as the most frequently implicated factor for reduced silage DM intake (Cushnahan and Gordon, 1995; Patterson et al. 1996). A recent review by Wright et al. (2000) examined the relationship between wilting and silage DM intake. These authors concluded that ammonia concentration was correlated with the difference in intake of unwilted and wilted silages ($r^2 = 0.24$). Other significant variables, drying rate ($r^2 = 0.39$) and water loss ($r^2 = 0.34$), however, were more important.

Studies re-analysing large data sets from European research centres have concluded that CP level (up to about 18%) and fibre were primary determinants of silage intake but fermentation characteristics played a modifying role (Rook and Gill, 1990; Rook et al. 1990, Steen et al. 1995, Steen et al. 1998). Broadly, this conclusion supports the original hypothesis of this review – when

populations of silages are concerned, digestibility is important, however, within silages of similar digestibility, fermentation end-products have a modifying effect. Rook and Gill (1990) concluded that total VFA improved prediction but ammonia concentration was of minor importance. On the other hand, Steen et al. (1995) concluded that ammonia was an important predictor of silage DM intake. These discrepancies probably relate to the different populations of silages used in the two assessments. Interestingly, lactic acid, pH and DM concentration in themselves were deemed not to be important determinants of silage DM intake. Early studies concluded that these were important probably because of their close relationship with causal factors (e.g. silage of low DM content usually contains a broad spectrum of VFA).

Given the evidence presented above, it is difficult to suggest how silage intake is related to concentrations of carbohydrate fermentation end products. Despite over 40 years of research there is still no definitive agreement as to which factor(s) are responsible.

Protein solubility and rumen ammonia

Ruminal ammonia levels, on the other hand, may have an impact on silage DM intake. After feeding silages, ruminal ammonia concentration can increase to 80 mg dl^{-1} (Charmley and Veira 1990a). These very high levels are not related to the level of ammonia in silage, but to the amount and solubility of CP in silage. Thus silages with a high CP content and high solubility, such as alfalfa, can result in high rumen ammonia concentration (figure 3a). Under certain feeding situations, these conditions could lead to mild ammonia toxicosis which may reduce feed intake (Choung et al. 1990). Figure 3a shows a close relationship between the intake of non-protein N in sheep and rumen ammonia, while Figure 3b shows that as rumen ammonia increases above 25 mg dL^{-1} then silage DM intake declines. These data would suggest that there should be a strong relationship between non-protein N in silage and silage DM intake.

Charmley and Veira (1990a and b) used high temperature-short term heat treatment to denature plant protease enzymes in alfalfa. This treatment dramatically reduced the solubility of CP in the silage and increased intake (Table 2). Similar responses in DM intake by reducing protein solubility have been achieved when rapid acidification (Charmley et al. 1995) or wilting (Muck, 1987) have been used to inhibit proteolytic activity.

THE INFLUENCE OF SILAGE FERMENTATION ON UTILIZATION OF PROTEIN AND ENERGY

Protein Utilization

Silage protein quality represents perhaps the most important determinant of silage nutritive value from an economic standpoint in North America. This is because most producers are ensiling crops at early maturity when digestibility is high. At this stage of growth, CP content and solubility are high (Tamminga et al. 1991; Van Vuuren et al. 1991). It is particularly an issue for alfalfa silages

because alfalfa contains high levels of enzymes which solubilize protein through hydrolysis to amino acids (Papadopoulos and McKersie 1983). By comparison, red clover protein is hydrolysed at only 20% the rate of alfalfa protein (Jones et al. 1995).

Research has shown many times that silage-based diets need supplemental protein whether given to growing cattle (Veira et al. 1985, 1990, 1994), dairy cattle (Robinson et al. 1992; Broderick 1995a) and even beef cows (Charmley et al. 1999b). This is attributed to the poor efficiency with which silage protein is used in the rumen (ARC 1983). Thus, supplementation with a relatively undegraded protein source can increase production through increased UIP supply (Broderick 1995b) and through increased silage intake (Gill et al. 1987) and digestibility (England and Gill 1985). Poor efficiency not only necessitates expensive protein supplementation, but also creates excessive excretion of surplus N into the environment (Dhiman and Satter, 1997). This can be of concern in intensive ruminant livestock production areas (Tamminga et al. 1991; Broderick 1995a).

Poor N utilization from silages is a product of two consequences of ensilage: solubilization of protein and fermentation of soluble sugars to VFA and lactic acid. Energy yield and utilization from VFA and lactic acid is considerably less than from non-fermented carbohydrate (Thomas and Thomas 1985). A very high proportion of VFA are absorbed directly across the rumen wall and not utilized by rumen microbes. Thus the efficiency of utilization of fermented organic matter for microbial protein synthesis is only approximately 60 to 70% of that for energy from non-fermented feeds (ARC 1984).

Since silage fermentation depletes soluble carbohydrate concentration, many researchers have added sugars back to silage rations in an attempt to improve protein utilization (Chamberlain et al. 1985; Charmley et al. 1991; Khalili and Huhtanen 1991). Results have been equivocal. Chamberlain et al. (1985) concluded that sucrose supplementation improved efficiency of microbial protein synthesis in limit-fed sheep. However, ruminal fermentation patterns under these conditions are characterized by extremes in rumen ammonia concentration and are not conducive to efficient ammonia capture by rumen microbes. Such conditions are not found in animals fed ad libitum (Charmley et al. 1991). Khalili and Huhtanen (1991) concluded that the beneficial effects of sucrose on the amounts of amino acids reaching the intestine was due to increased ruminal turnover rate rather than improved microbial efficiency. In support of this Keady and Murphy (1998) found that sucrose supplementation alone did not increase intake or milk yield of dairy cows, but when sucrose plus fishmeal was fed there was a response.

In addition to poor efficiency of microbial protein synthesis, the proportion of dietary proteins escaping degradation in the rumen are also low for forages in general and silages in particular (Tamminga et al. 1991). Tamminga et al. (1991), in a survey of 35 grass silages, found that between 40 and 70% (average 61%) of CP was instantly solubilized in the rumen and only 4 to 24% was undegradable (average 9%). In comparison, for hay only 32% was immediately solubilized with 12% undegradable. Charmley and Veira (1991), showed that the problem of high N solubility was not attributed to microbial fermentation but to proteolysis by plant enzymes. Plant enzyme systems were inhibited by short-duration heat treatment which reduced protein solubility, increased CP flow to the

duodenum and increased CP gain in lambs (Table 2). In practical terms, plant proteolysis can be restricted by reducing pH or by increasing DM content of silage. However, to be effective both processes have to occur within hours of cutting. Agbossamy et al. (2000) have demonstrated this clearly in a trial comparing different degrees of maceration at mowing, which increases drying rate. As maceration intensity increased so did drying rate and protein solubility (Figure 4).

Charmley and McQueen (unpublished) demonstrated that both wilting and rapid acidification have an effect on protein solubility, however these effects were only partially additive. This study employed three levels of acid treatment (0, 5 and 10 L carboxylic salts/t crop) and three wilting periods under good drying conditions (0, 24 and 48 h). The results are summarized in Figure 6 and showed that extensive wilting combined with the highest rate of additive, preserved 80 % of the original protein N present in the crop at ensiling. This compared with less than 40 % of the original protein N being preserved when no wilting or additives were employed. The potential for a combined approach to inhibiting proteolysis appears real. This would be especially beneficial if reducing protein solubility not only improves N utilization, but also increases intake of silages, as proposed earlier.

Considering the highly soluble nature of silage protein, it is surprising that a degradable protein source can also increase production. Robinson et al. (1992) fed high-silage (85 to 90%) diets supplemented with bloodmeal and casein in varying proportions. Casein was more effective than bloodmeal at increasing milk production and this was attributed to increased microbial protein synthesis in response to a ruminal supply of soluble peptides from casein. Other work has confirmed that peptides may be limiting in silage diets where much of the protein is in the form of amino acids (Newbold et al. 1991; Choung and Chamberlain 1993a). Thus, stimulating rumen fermentation and microbial protein synthesis with degradable protein may be as effective as supplementing it with undegraded protein. In addition these two approaches can be use additively.

Carbohydrate Utilization

Fermentation of non-structural carbohydrate in silage has a direct effect on the pattern of VFA production in the rumen. Silages that have undergone an extensive homolactic fermentation contain almost no soluble sugars, however, in excess of 10 to 15% of the DM can be as lactic acid. In addition, 3 to 6% of the DM can be as VFA. In the rumen, VFA are absorbed directly and lactic acid is metabolized primarily to propionate. This shifts the balance of fermentation end products away from lipogenic to glucogenic pre-cursors (Jaakkola and Huhtanen 1992; Martin et al. 1994). The effect can be so marked as to reduce milk fat concentration (Cushnahan and Mayne 1995; Keady and Murphy 1996). Whereas in the past this was regarded as a problem, today it may be possible to exploit this as a tool to modify milk composition.

Relatively little attention has been drawn to the fact that ensiling can result in the conversion of structural carbohydrate to non-structural carbohydrate by plant enzymes (Heron et al. 1986). The extent of this phenomenon is clearly seen with aseptic silages (i.e. no microbial population). Charmley and Veira (1991) more than doubled initial water soluble carbohydrate concentration in

aseptic silages which had been irradiated with gamma radiation (Fig. 5). Further, enzymic hydrolysis may be augmented by acid hydrolysis of structural carbohydrate, particularly in highly fermented silages (Heron and Owen 1991). This represents a major source of substrate for silage and possibly rumen microbes. It also explains why the energy in fermentation acids often exceeds that in the original WSC. Considering this phenomenon, it is likely that initial WSC levels are less critical to the success of fermentation than often thought. The role of direct addition enzymes in this area is obvious, however increased cell wall degredation in the silo is often accompanied by reduced cell wall degredation in the rumen (Sheperd et al. 1995; Nadeau et al. 1996)

MEASURES TO IMPROVE SILAGE INTAKE AND UTILIZATION

In the foregoing review, certain key elements have been shown to be critical in determining the feeding value of silage – voluntary intake, protein quality and carbohydrate fermentation. Methods of manipulating these key elements will now be considered.

Restricting fermentation through wilting

There are two means of restricting fermentation; wilting and the use of acid-type additives. Wilting, to some extent, is almost universally used in North America. However, the degree of moisture loss and the wilting conditions vary, depending upon climate and prevailing weather conditions. Wilting indiscriminately reduces microbial activity in silage, thus restricting the extent of fermentation. However, it also tends to favour lactic acid bacteria over other types, thus reducing the risk of less useful microbial pathways dominating the ensilage process (McDonald et al. 1991). Research from the 1980's and before suggested that intake of silage was increased by wilting (e.g. Marsh 1979; Zimmer and Wilkins 1984). However, in many of those studies animal performance was not improved (e.g. Charmley and Thomas 1987) and this was attributed to reduced digestibility in wilted compared with unwilted silage, and reduced efficiency of energy utilization (Unsworth and Gordon, 1985). From other work, particularly with inoculant-treated silages, this digestibility effect now seems to be due to an increase in digestibility of more extensively fermented silages rather than a reduction in digestibility due to wilting (Cushnahan and Gordon 1995). This may be attributed to hydrolysis of structural carbohydrate (Dewar et al. 1963), modified intake and rumen outflow patterns (Thiago et al. 1992) or a combination of both. Rook and Gill (1990) in an analysis of European research, concluded the response to wilting was curvilinear with no benefits seen when DM content was above about 25 % DM. However, in a more recent review, with a wider set of data from 79 comparisons the response to increasing DM content in the wilted silage was linear (Wright et al. 2000). Dawson et al. (1999) showed that the greatest response to wilting was achieved under good drying conditions. Wright et al. (2000) also concluded that wilting rate, and the extent of moisture loss in wilted silages were variables most highly correlated with improved intake and performance from wilted silage relative to unwilted silages. This suggests that benefits to the animal are greatest under good wilting conditions.

It is known that wilting markedly reduces proteolysis by plant enzymes in the silo (Muck 1987,

1989). The faster the rate of drying, the more effective wilting is at reducing proteolysis (Anderson 1983). As noted previously, animal studies have linked this reduction in protein solubility to increased amino acid flow to the intestines (Charmley and Veira 1990a,b), and milk yield in lactating cows (Broderick et al. 1993). Thus the benefits of wilting on animal performance may be related primarily to an improvement in the utilization of N by the ruminant.

Based on this review, it would appear that methods to increase drying rate will have a profound effect on animal performance. Such methods include crop spreading, to expose the maximum surface area to solar radiation (Wilkinson et al. 1999), and crop conditioning to reduce plant resistance to moisture loss (Savoie et al. 1993; Frost and Binnie 1999). Wilkinson et al. (1999) increased drying rate by spreading swaths during wilting. Such swaths reached a higher DM concentration by ensiling. A response in intake by dairy cows was observed, but it is difficult to conclude if this was due to drying rate or the DM content at which forage was ensiled.

In studies where macerated forage has been ensiled and fed to ruminants, the effect of maceration on intake, digestibility and animal performance has been mixed. Frost et al. (1995) found that intake of ryegrass silage by sheep was reduced by maceration. However, Charmley et al. (1997) found no effect on intake or digestibility of alfalfa silage by sheep. Mertens and Koegel (1992) show that although maceration reduced silage intake in dairy cows, milk production was unaffected, suggesting better utilization of silage. Suwarno et al. (1997) observed that intake by cattle fed round bale silage was increased by maceration. Charmley et al. (1999a) found that in round bale silage there was no effect on intake but animal gain was improved by maceration. When the same forage was fed as precision chopped silage, intake was reduced by maceration. From these results it can be concluded that in precision chopped silages, intake is not generally increased by maceration, and can often be decreased. Nevertheless efficiency of utilization appears to be improved. By contrast, the response is different in unchopped forage, such as round bale silage and hay (Petit et al. 1994; Savoie and Block 1994). A positive response is often observed. This suggests that maceration may mediate increased intake through a physical effect, whereas modification to chemical (fermentation) characteristics may influence efficiency of utilization. Variation in response to maceration must also reflect the variation in the degree of maceration among trials and the degree of improvement in drying rate achieved (Suwarno et al. 1999; Agbossamy et al. 2000).

Restriction of fermentation through acidification

Acid-type additives have a similar effect on proteolysis to wilting by inhibiting plant protease enzymes through rapid reduction in pH (Chamberlain and Quig 1987; Charmley et al. 1995; Keady and Murphy, 1997). Charmley et al. (1994) demonstrated this by using three levels of acid salts on wilted alfalfa (Table 3). Results showed that proteolysis was progressively restricted as the level of additive was increased. This translated to improved growth of steers fed the same quantity of silage. Similar results have been obtained with dairy cows. For example, Nagel and Broderick (1992) increased insoluble protein in alfalfa silage with formic acid and this increased milk production by 12% (Table 4). Added acids are more effective than natural fermentation because acidification occurs within minutes of adding the additive. When relying on natural fermentation, acidification

can take days or weeks.

Enhancing silage fermentation by inoculation and enzymes

Within recent years, inoculants and enzymes have become popular as a means of improving silage nutritive value. Interestingly, these work in opposite fashion to wilting in that they increase the extent of fermentation in the silo, rather than reduce it (Bolsen et al. 1992).

In a review of data up to the end of the 1980`s, Spoelstra (1991) concluded that inoculation increased animal performance from silages by about 7%. Muck (1993) also reached a similar conclusion, noting a 5% improvement in milk production following inoculant use. Both reviewers concluded that a large part of the improvement in performance was due to an increase in digestibility, rather than an increase in intake. This was contrary to what was expected, since lactic acid bacteria (the principle bacterial type in inoculants) are non-cellulolytic. The increase in digestibility may be in response to the extensive fermentation of substrate to lactic acid in these silages. Under these conditions, acid hydrolysis of structural carbohydrate to soluble sugars will occur (Dewar et al. 1963). The reduction in fibre concentration has been speculated to be responsible for increases in digestibility (Heron and Owen 1991). On the other hand, Gill and Romney (1994), Thiago et al. (1992) and Teller et al. (1993) have demonstrated that highly fermented silages are eaten more slowly than less highly fermented silages or hay. If these changes in eating behaviour influence ruminal retention time, then this could also explain why digestibility is increased by inoculant use.

A possible direct, probiotic effect of silage inoculation on rumen fermentation has been proposed (Gordon, 1989) to explain improved animal performance from inoculated silages, in the absence of changes in silage fermentation. However, when Keady and Steen (1996) added *Lactobacillus plantarum* bacteria at 10^9 cfu g^{-1} silage at the time of feeding, they found no animal response in terms of intake, digestibility or rumen fermentation.

Evidence is increasing to suggest that lactic acid in silage favours a glucogenic balance of VFA in the rumen (Martin et al. 1994). In certain trials this has led to a reduction in milk fat percent (Cushnahan and Mayne 1995). If this proves to be a widespread phenomenon, inoculants may play a role in reducing milk fat percent.

Cellulase, hemicellulase and amylase enzymes have been widely tested as silage additives. These compounds have the potential to convert structural carbohydrate to soluble sugars which can be fermented by silage bacteria. Many trials have shown that their use increases the level of fermentable substrate in silage, thus promoting extensive fermentation (Jaakkola et al. 1991; Jacobs and McAllan 1991; Stokes 1992). However, for most European research with relatively wet silages, there has not been an increase in digestibility and improvements in animal performance have been generally small (Jaakkola et al. 1991; Jacobs and McAllan 1991). This may be attributed to increased effluent losses, removing soluble compounds from the silage, since research with wilted silages has shown benefits in digestibility and animal performance (Fredeen et al. 1991; Fredeen and McQueen 1993; Stokes et al. 1993). Effects on animal performance are consistent with enhanced fermentation and similar

to those reported for inoculants. However, increased hydrolysis of structural carbohydrate in the silo results in reduced fermentation of structural carbohydrate in the rumen (Sheperd et al. 1995).

CONCLUSIONS

Modern ensiling technology has increased the feeding value of silages close to that of the original unensiled forage. However, silages of poorer feeding value are still produced and there is no consensus on what factor(s) are critical to silage feeding value. Concentrations of fermentation acids do not seem closely related to silage intake, however they are critical in determining the balance of VFA produced in the rumen. This in turn, affects the non glucogenic ratio and can influence milk and body composition in productive livestock. While rumen ammonia is often implicated in reducing silage intake, protein solubility may be more the cause than ammonia per se. Protein solubility is also a major factor in reducing the efficiency of silage protein utilization. Given that protein solubility is implicated in both the voluntary intake of silages and the utilization of protein in silage, it is surprising that this aspect has not received more attention, particularly in Europe. Methods shown to improve silage feeding value include effective wilting and rapid acidification, either by direct acidification or use of inoculants. Their widespread adoption has undoubtedly contributed to improvements in animal production from silages in recent years. The possibility that in future, silages will have superior feeding value to the original crop is realistic. Physical treatments can break down barriers to intake and improve digestibility. Predictable silage fermentation can be used to optimize rumen function. However, there appears to be less scope for improving on the protein quality of the original forage.

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Table 1. Indices needed to define silage quality

Quality category	Index of quality	Routine analysis[z]
Crop related factors	Crude protein	*****
	Acid detergent fibre	***
	Neutral detergent fibre	***
	Total digestible nutrients, net energy	[*****]
Fermentation related factors	pH	**
	Protein solubility	**
	Organic acid content and profile	*
	Water soluble carbohydrate	*
	Ammonia	*

[z] ***** = almost always reported to * = almost never reported. Parentheses indicate that value is not measured directly.

Table 2. Effect of inactivating plant enzyme activity using heat on protein solubility, CP flow to the duodenum and performance of growing lambs.

	Control	Heat-treated
Protease activity of forage (units $g^{-1}h^{-1}$)	1.23	0.42
Insoluble crude protein (% CP)	33	61
Digestion study[z]		
CP intake (g d^{-1})	215	201
CP flow to duodenum (g d^{-1})	151	182
CP lost across rumen (g d^{-1})	64	19
Growth study[y]		
DM intake (g kg^{-1} BW)	28	37
Carcass gain (g d^{-1})	3	40
CP gain (g d^{-1})	0.4	17

[z] Charmley and Veira (1994a)
[y] Charmley and Veira (1994b)

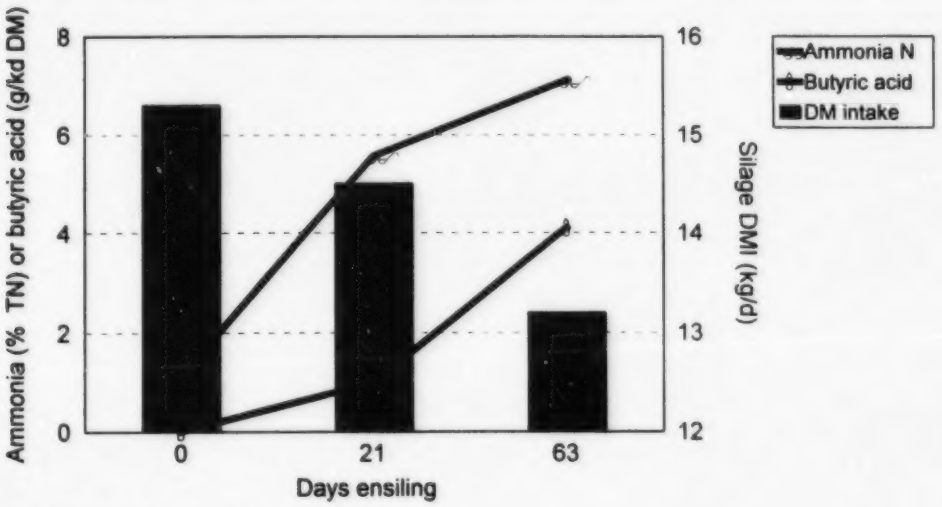
Table 3. Effect of direct acidification of silage on crop proteolysis and performance of growing steers fed alfalfa silage

	Additive rate (L carboxylic salts t^{-1})		
	0	4	8
DM at ensiling (%)	34	32	34
Crude protein (% DM)	18	18	18
Insoluble CP (% CP)	41	55	60
DM intake (g kg^{-1} BW)	31	29	30
Gain (kg d^{-1})	0.74	0.86	0.87

Table 4. Effect of direct acidification of silage on crop proteoylsis and milk production in cows fed alfalfa silage

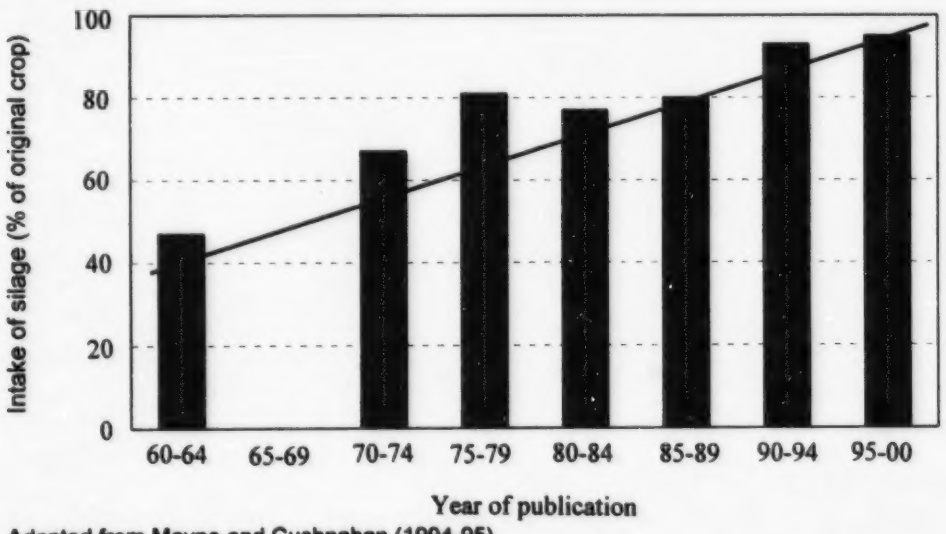
	Additive rate (L formic acid t^{-1})	
	0	8
DM at ensiling (%)	38	35
Crude protein (% DM)	21	21
Insoluble CP (% CP)	57	71
DM intake (kg d^{-1})	18	18
Milk production (kg d^{-1})	29	33

Figure 1. Relationship between silage fermentation and voluntary intake



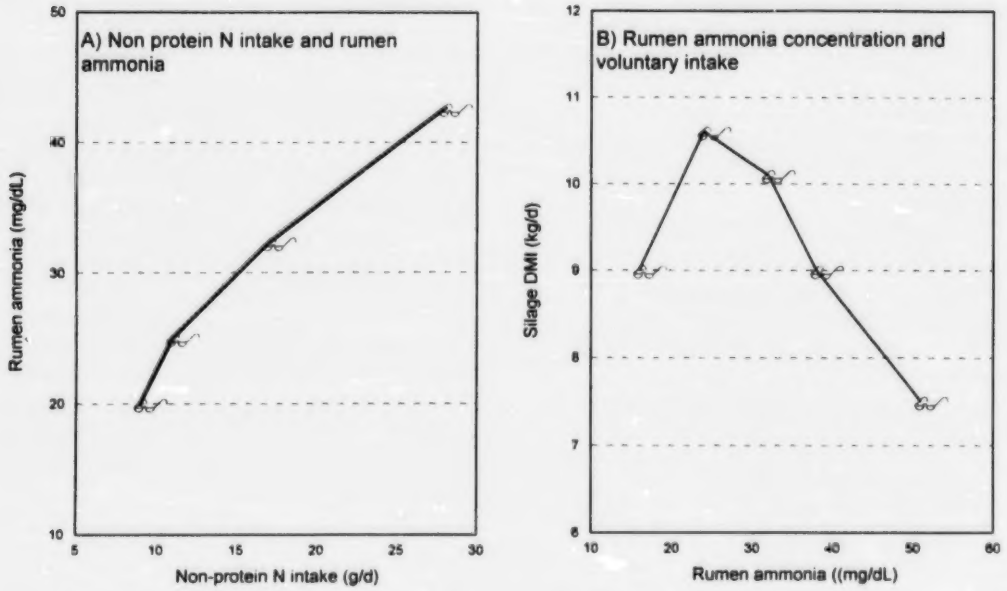
Cushnahan et al. (1995)

Figure 2. Relative intake of silage compared with original crop



Adapted from Mayne and Cushnahan (1994-95)

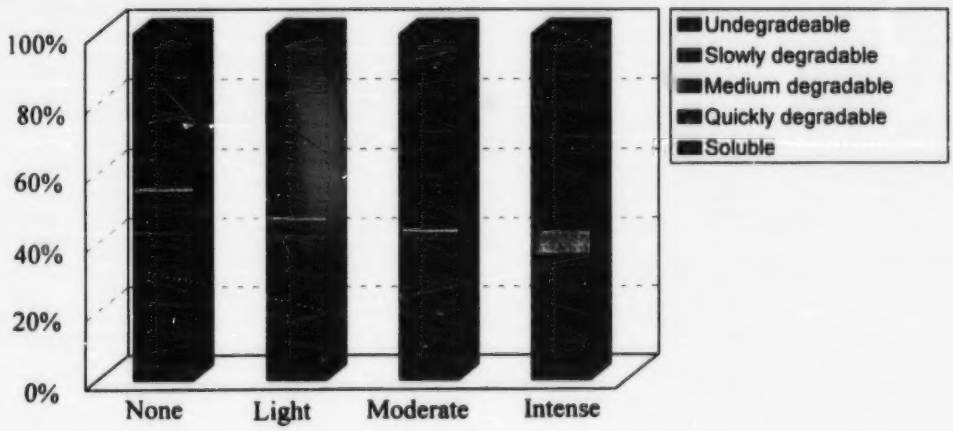
Figure 3. relationship between protein solubility and voluntary intake of silage


A) Non protein N intake and rumen ammonia
Rumen ammonia (mg/dL)
Non-protein N intake (g/d)
B) Rumen ammonia concentration and voluntary intake
Silage DMI (kg/d)
Rumen ammonia ((mg/dL)

Charmley and Veira, (1990a)

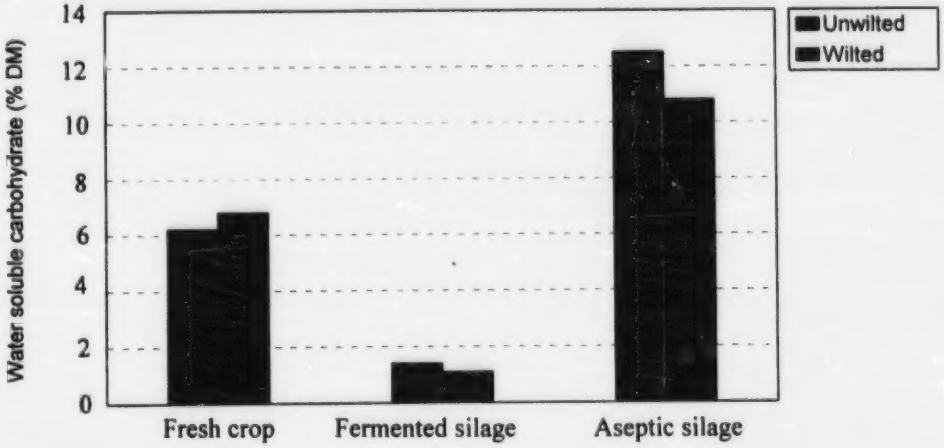
Choung et al. (1990)

Figure 4. Effect of degree of maceration on protein degradability in silage



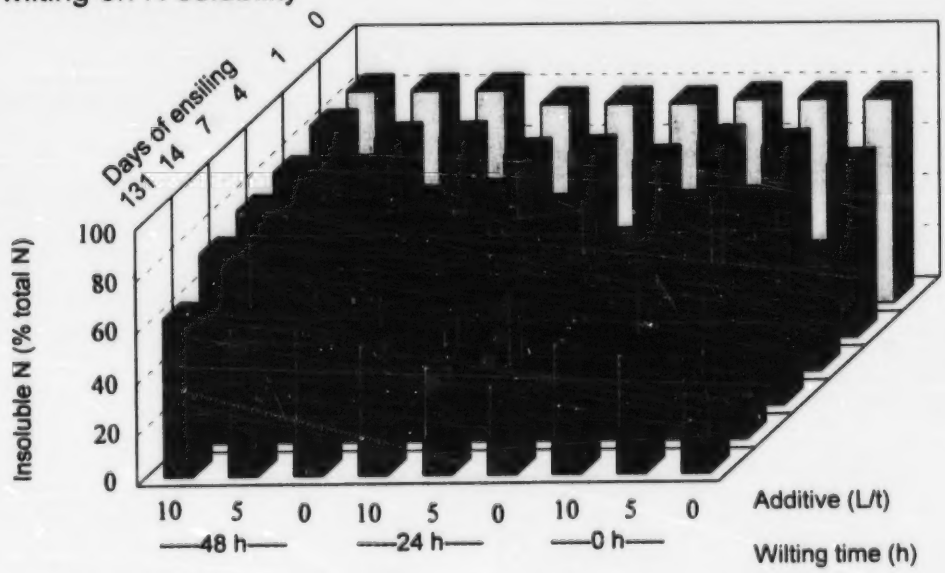
Agbossamey et al. (1998)

Figure 5. Soluble sugar accumulation in aseptic silages produced from unwilted and wilted alfalfa.



Charmley and Veira (1991)

Figure 6. Effect of direct acidification in combination with wilting on N solubility



Charmley and McQueen (unpublished)

July 20 / 20 juillet 2000
15:30 to 17:00

Session 4: Forage Feed Value

Thème 4: Valeur nutritive des fourrages

Moderator / Modératrice: Wanda McFadyen

FEED VALUE OF ROUND BALE SILAGE FOR CATTLE

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INTRODUCTION

Round bale silage has become one of the most popular system of silage making in developed countries (Ohlsson, 1998). The main advantages of round bale silage over conventional silage systems are its greater flexibility with regard to harvest date and desired forage quality. The possibility to quickly bale and wrap small quantities of grass allowing for more flexibility in terms of ration formulation and reduced capital investment for equipment and storage.

In spite of its popularity, relatively little scientific information on the ensiling characteristics and feeding value of round bale silage compared with conventional silage has been published (Nicholson et al., 1991; Petit et al., 1993; Charmley et al., 1999). This paper will present results from a series of experiments conducted at the Beef Research Farm in Kapuskasing, Ontario. They were designed to compare the nutritive value of round bale silage with that of conventional silage and to determine the effect of different factors (DM level at ensiling, particle length) on the feeding value of round bale silage.

Effect of conservation mode on the performance of growing cattle - Intake and growth

The first experiment was designed to compare performance of growing cattle fed silages stored in heap silos (HS) or round bales (RB). Sixteen bull calves, with an initial body weight of 255 kg (± 22 SD), were divided in two groups and fed red clover silage conserved in HS (25.1% DM; table 1) or in RB (40.3% DM). Individual daily intake was calculated for 98 days. Bulls fed RB silage ate 35% more DM (8.0 vs 5.9 kg d^{-1}; SEM = 0.4) when compared to those fed HS. However, average daily gain (ADG) was not affected (0.65 kg d^{-1}; SEM = 0.05). This led to a significant deterioration ($P<0.01$) in feed efficiency for steers fed RB silage (12.8 vs 9.0 kg DMI/kg ADG; SEM = 0.8). It has been reported that dry matter intake increases with increasing DM concentration (Demarquilly, 1990) but in the present experiment, the higher level of ingestion did not lead to a better ADG for the animals fed RB silage than for those fed HS. One may suggest that the energy required to eat long fiber provided by the RB may reduce the energy available for gain (Osuji et al., 1975). Nicholson et al. (1991) attributed a similar decrease in feed efficiency, when baled silage was compared to chopped bag silage, to the fermentation pattern. In the present experiment, silage characteristics presented in table 1 indicated that HS was lower in DM and soluble sugars but higher in NDF and ammonia-N content when compared to RB silage. The last two parameters could partly explain the lower DM intake of steers fed with the HS since NDF (Mertens, 1973) and silage

ammonia-N (Beever and Siddons, 1986) are negatively associated with voluntary DM intake. Although no measurement was applicable, visual observation of the area close to the trough seemed to indicate a certain amount of losses caused by spilling of long fibrous particles.

Effect of conservation mode on the performance of growing cattle - Rumen digestibility

A nylon bag study (Veira et al., unpublished data), conducted concomitantly with rumen fistulated heifers fed the same diet, indicated that for DM, fraction "a" (instantly degraded; Ørskov and McDonald, 1979) tended to be lower for the RB silage as compared to the HS (table 2) but fraction "b" (slowly degraded) was higher. Degradation rate (fraction "c") of DM was lower for RB. Nitrogen fraction "a" was 18% lower for the RB silage. N fraction "b" was no affected but degradation rate "c" tended to be lower for RB silage. Degradability of fraction "b" tended to be higher for NDF provided from the RB. NDF rate of degradation (fraction c) was lower fro RB silage. Overall, DM and NDF effective degradability were not affected for both parameters. Effective degradability of N was decreased when silage was conserved as RB (table 2) mostly because fraction a was less degradable.

Effect of conservation mode on the performance of growing cattle - Replacement heifers

A second experiment was planned to compare RB silage and HS for replacement beef heifers. For this experiment, 40 weaned heifers (20 medium frame and 20 large frame) averaging 208 kg of BW (21 SD) were divided at random in four groups. Heap silage was fed ab libitum and RB were offered free choice during 98 days (table 3). Dry matter content of silages were 25.8 and 34.8% (SEM = 0.8) for HS and RB, respectively. Average daily gain, 0.70 kg d^{-1} (SEM = 0.03), was not affected ($P<0.10$) by silage type or by frame size. No significant interaction was observed between frame size and silage type. Although comparisons between treatments for the daily dry matter intake are limited, a higher numerical value was recorded for heifers fed RB when compared to HS (6.56 vs 6.02 kg DM/d for RB vs HS, respectively). Again, visual observation indicated that some loss of forage occurred when the RB were fed. This could partly explain the higher intake of heifers fed RB silage.

Effect of round bale silage on total tract digestibility

Concomitantly, six steers (270 kg of BW) were used to determine the apparent digestibility of the diet. During the digestive study, silage DM was similar (28.9 and 28.7%; SEM = 0.9 for HS and RB, respectively). Nitrogen apparent digestibility was not affected by treatment (65.9 vs 68.8%; SEM = 1.1 for HS vs RB, respectively). However, N retention expressed as percentage of N intake was improved ($P<0.05$) when animals were fed HS (27 vs 22%; SEM = 1). When N retention is expressed as percent of absorbed N (N retention / [N intake -N lost in faeces]), this term was higher (40.8 to 31.5%; SEM = 1.1; $P<0.01$) for animals fed HS than those fed RB silage. Apparent digestibility of NDF tended to increase ($P<0.10$) when HS was fed (71.1 vs 67.4% ; SEM = 1.2) while ADF was not affected and averaged 64.7% (SEM = 0.6). If we assume that higher NDF digestibility will improve microbial synthesis in the rumen this could explain the more efficient use

of N for steers fed HS in this experiment.

Effect of round bale silage on female reproductive function and performance

In a third trial, HS and RB silage were compared when fed to a cow-calf herd where animals are kept outside during winter. Ninety cows (610 kg; SEM = 5) with their calves born in September were randomly assigned to 9 groups of 10 cows. Six groups of animals were fed during 120 days with HS (24% DM) and another 3 groups received RB (34%) silage. Heap silage was fed once a day while RB silage was provided when needed. Body condition score and backfat measurements were recorded at the beginning, 1 week before the beginning of insemination and at weaning. Reproductive performances were also evaluated. Cows fed RB silage ingested more DM (3.1% of their body weight) as compared to cows fed HS (2.0% of BW; $P<0.001$). Calves intake, if any, was indirectly attributed to cows. Cows fed the RB silage tended ($P=0.12$) to gain body weight (20 kg) while cows fed HS lost 5 kg. Calves from cows fed RB silage had similar average daily gain than those from cows fed HS (0.88 vs 0.82 kg d^{-1}; SEM = 0.09; $P>0.05$). When silage intake and the total kg of gain (cow-calf pair) were compiled, similar values between treatments were obtained for the average daily gain and feed to gain ratio ($P>0.05$). A summary of steer, heifer and cow-calf trials is presented in table 4. In average, animal fed RB ingested 32% more DM, gained 10% more but required 26% more feed per kg of gain when compared with those fed HS.

Reproduction data indicated that there was a tendency ($P<0.10$) for an increase in calving interval (377 vs 373 days; SEM = 1) when cows were fed HS as compared to those fed RB silage. No significant effect of treatments on days from calving to first service (94 days; SEM = 1) or days open (99 days; SEM = 5) was observed. The increase in calving interval for cows fed HS could be related to their weight loss. Short et al. (1990) reported that energy deficit could partly explain a reduction in animal reproduction performance. However, it remains unclear why cows fed HS lost weight.

Effect of dry matter content on round bale silage utilization

Unfortunately, in the trials reported above, the effect of dry matter content was confounded with the effect of conservation mode. Thus, another experiment, with cow-calf pairs was designed to evaluate the effect of dry matter content of RB on silage fermentation and animal performance. Three different silages were harvested. One HS was harvested at 32% DM, a second silage harvested simultaneously and stored in RB contained 39% of DM and the last one was also a RB silage but wilted to 52% of DM. As shown in figure 1, a significant ($P<0.05$) reduction in DM losses occurred when the wilted RB silage was compared to the other two treatments. Silage characteristics indicated that a larger proportion of nitrogen was in the form of protein in the HS than the two RB silages, the low DM RB having less N in protein form (table 5). However, fermentation characteristics between the two types of RB silage were similar (data not shown). There was no difference between HS and the RB silages on animal performance. However, cows fed the wilted RB silage had a numerically higher gain and backfat thickness increment when compared to the high moisture RB silage (table 6). Calf average daily gain was similar between rations and averaged 1.07 kg/d.

Effect of dry matter content and particle length on total tract digestibility

Dry matter digestibility was also measured using steers in a 6 x 6 Latin square design. Treatments consisted of low or high DM RB silages used for the cow-calf experiment which were fed long (as harvested; 25 cm approximately) or chopped (2.5 cm approximately) before feeding, the HS was fed as harvested and a second HS was added as a positive control given that it was very well preserved. No difference in digestibility parameters was observed between HS and the high moisture RB (data not shown). However, dry matter digestibility was significantly affected ($P<0.05$) by the moisture content of RB; the high moisture content being more digestible (73.2 vs 70.3%; SEM = 1.2, for RB39% vs RB52% respectively). The NDF and ADF apparent digestibility were not affected by treatments. Energy digestibility tended ($P<0.10$) to be higher in the high moisture silage (68.1 vs 65.1%; SEM = 1.5, for RB39% and RB52%, respectively). When compared to RB39%, cows fed the high dry matter RB had a lower coefficient of nitrogen digestibility (60.2 vs 68.7%; SEM = 2.3; $P<0.001$). This could explain the tendency ($P<0.10$) for a lower N retention of cows fed RB52% (19.9 vs 28.6 g d^{-1}; SEM = 4.6). The digestibility coefficient suggested a better efficiency in the use of high moisture RB silage when compared to the wilted RB silage. However, performance of the cows and calves were in favour of the wilted silage probably because of higher intake. As expected (Petit and Flipot, 1990), higher N retention was observed when shorter particle length silage was fed (24.6 vs 18.7% N retained per N ingested; SEM = 3.0; $P<0.10$) or expressed as N absorbed (38.4 and 27.2% of N absorbed; SEM = 5.5; $P<0.05$).

Can we improve animal performances with higher density round bale silages?

We hypothesized that particle length could have an important effect on feed efficiency. To test this postulate, a second-cut orchardgrass was harvested with round balers either equipped or not with a cutting device. As expected, results indicated that chopped bales were heavier than control bales (183 vs 149 kg DM m^{-3}; SEM = 26; $P<0.01$) given that geometric mean size of particles from chopped was shorter than control bales (23 vs 30 cm; SEM = 2; $P<0.05$). Dry matter losses and fermentation characteristics were not affected by the utilization of a cutting device. In a performance trial, 24 cow-calf pairs, assigned to chopped or control bale silage showed similar growth rates of calves (1.05 and 1.13 kg/d for chopped and control, respectively) and cows (0.43 vs 0.38 kg/d for chopped and control, respectively). Intake and feed efficiency were similar among treatments. We concluded that although the baler equipped with a cutting device produced heavier bales because of a reduction in forage particle size, this reduction was not sufficient to have a significant effect on animal performance. Considering this information, the effect of particle length on feed efficiency needs to be further investigated in a project where particle length would be reduced more drastically.

CONCLUSION

Our results confirm that fermentation is limited in RB silage, especially when wilted prior to ensiling (Nicholson et al., 1991). RB silage displayed a restricted fermentation characterized by a higher pH, lower concentration of lactic acid and higher levels of residual sugars. Proteolysis was also

diminished in RB silage as evidenced by lower proportions of ammonia-N. When determined *in situ* rumen degradability of N was lower for RB silage.

Average daily gains were not affected by the type of silage fed. However, higher levels of DM intake for cattle fed RB silage contributed to a significant reduction in feed efficiency as observed by others (Charmley et al., 1999). In these trials it took between 8 and 45% more dry matter from round bales to make 1 kg of gain. This is in close agreement with values reported by Nicholson et al. (1991) and Charmley et al. (1999).

When compared to HS, digestibility parameters of RB silages seemed marginally affected. Therefore, we suggest that the long particles in RB silage have an effect on DM intake and forage residence time in the rumen. This suggestion is supported by Amyot (1988) who reported a significant increase in DM intake and milk when RB silage was chopped (5-7 cm) before feeding.

From the producer point of view, RB silage could represent a good avenue to reduce labour at harvest and at feeding time without affecting animal performance. However, more dry matter will have to be harvested to feed the same number of animals since feed efficiency is deteriorated with RB silage. It appears that the amount of energy used in the field to chop the forage is compensated by an improvement in feed conversion by cattle.

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Table 1. Composition of heap silo or round bale grass silage fed to steers

	Heap silage	Round bale	SEM	Probability (P<)
pH	4.5	4.7	0.2	NS
DM (%)	25.1	40.3	1.1	0.01
Soluble sugars (% of DM)	2.81	6.09	0.41	0.01
NDF (% of DM)	53.3	45.4	1.8	0.01
ADF (% of DM)	38.5	34.1	0.9	0.01
CP (% of DM)	18.0	16.4	1.2	NS
$N\text{-}NH_3$ (% of total N)	7.8	4.5	0.7	0.01
Hot water insoluble N (% of total N)	53.2	53.7	4.3	NS

Means, n = 7; NS = not significant

Table 2. Rumen digestibility of nutrients from heap or round bale grass silage

	Heap silage	Round bale	SEM	Probability (P<)
Dry matter				
Fraction a	34.8	32.1	1.2	0.10
Fraction b	44.6	53.6	3.2	0.05
Fraction c	0.05	0.03	0.01	0.05
Effective degradability of DM*	58.2	54.0	1.1	NS
Nitrogen				
Fraction a	64.5	52.8	4.3	0.05
Fraction b	29.3	39.8	4.8	NS
Fraction c	0.06	0.05	0.01	NS
Effective degradability of N	81.6	73.9	1.7	0.01
NDF				
Fraction a	15.0	6.7	2.3	NS
Fraction b	57.9	84.7	10.4	0.10
Fraction c	0.03	0.02	0.01	0.05
Effective degradability of NDF	39.8	30.3	1.9	NS

Means, n = 5; NS = not significant
*passage rate of 4%

Table 3. Composition of heap silo or round bale grass silage fed to replacement heifers

	Heap silage	Round bale	SEM	Probability (P<)
pH	4.3	4.4	0.2	NS
DM (%)	25.8	34.7	0.8	0.01
Soluble sugars (% of DM)	2.40	6.86	0.2	0.01
NDF (% of DM)	54.0	51.0	1.3	NS
ADF (% of DM)	35.6	34.3	0.8	NS
CP (% of DM)	15.4	15.1	0.5	NS
$N\text{-}NH_3$ (% of total N)	6.5	5.1	0.4	0.05
Fermentation characteristics				
VFA (% DM)				
Acetate	9.5	1.5	0.4	0.01
Propionate	0.43	0.03	0.02	0.01
Butyrate	0.25	0.13	0.05	NS
Total VFA (% DM)	10.2	1.9	0.4	0.01
Lactate (% DM)	24.5	7.3	1.3	0.01
Ethanol (%DM)	2.8	2.1	0.3	NS

Means, n = 7; NS = not significant

Table 4. Summary of animal performance fed round bale silage (RB) or conventional heap silo(HS)

	Dry matter intake (kg/d)		Average daily gain (kg/d)		Feed conversion	
	RB	HS	RB	HS	RB	HS
Steer trial	8.0	5.9	0.62	0.65	12.8	9.0
Heifer Trial	6.6	6.0	0.67	0.74	10.5	8.4
Cow-calf trial (Pair data)	18.7	12.4	1.04	0.78	18.0	15.9
Average (% of difference RB vs HS)	+32		+10		+26	

Table 5. Composition of heap silo or round bale grass silage to evaluate dry matter content effect

	Heap silage (1)	Round bale (2)	Round bale wilted (3)	SEM	Probability (P<)	
					1 vs 2	2 vs 3
pH	4.40	4.32	4.54	0.06	NS	0.05
DM (%)	32.1	39.6	51.7	2.3	0.05	0.01
Water soluble carbohydrates (% of DM)	1.9	2.9	3.5	0.4	NS	NS
NDF (% of DM)	46.6	46.6	50.3	1.9	NS	NS
ADF (% of DM)	30.2	30.3	31.7	1.1	NS	NS
CP (% of DM)	10.4	10.3	10.3	1.8	NS	NS
$N\text{-}NH_3$ (% of total N)	5.7	5.3	4.0	0.6	NS	NS
Hot water insoluble N (% of total N)	51.3	41.8	47.6	1.8	0.01	0.05

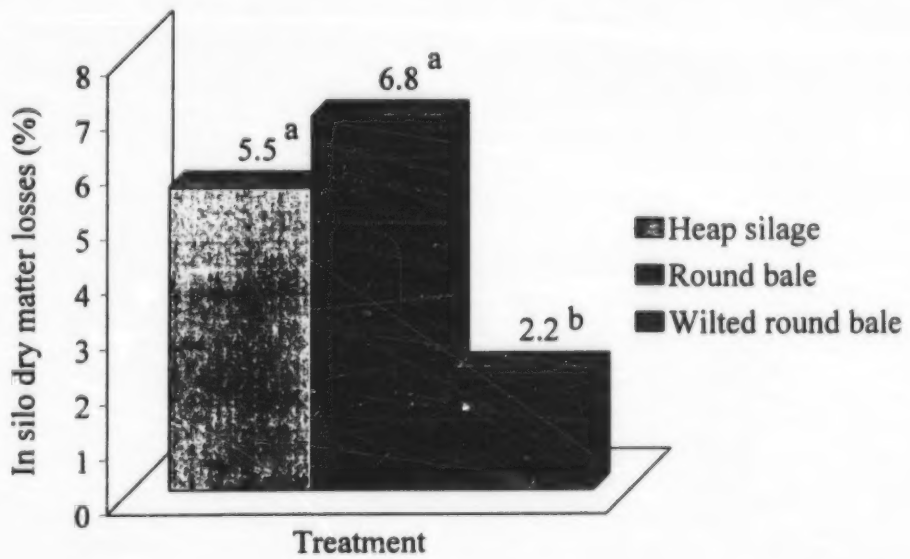
Means, n = 7; NS = not significant

Table 6. Effect of heap silo or round bale grass silage and moisture content (32-52%) on cow-calf performance

	Heap silage (1)	Round bale (2)	Round bale wilted (3)	SEM	Probability (P<)	
					1 vs 2	2 vs 3
Cow weight gain (kg/d)	0.24	0.24	0.50	0.12	NS	0.10
Backfat increment (mm)	1.97	0.51	2.62	1.1	NS	NS
Body condition score change (unit)	0.01	-0.07	0.18	0.20	NS	NS
Calf weight gain (kg/d)	1.11	1.02	1.09	0.08	NS	NS

Means, n = 10; NS = not significant

Figure 1. In silo dry matter losses during fermentation of heap or round bale or wilted round bale grass silage.



IMPORTANCE OF FORAGE IN RUMINANT DIETS TO INCREASE TISSUE CONTENT OF DESIRABLE FATTY ACIDS SUCH AS CONJUGATED LINOLEIC ACID ISOMERS

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ABSTRACT

Lipids derived from forages are predominantly of leaf origin. Lipids comprise 6-8% of the dry weight of leaf tissue, and are characterised by high content of glycolipid and phospholipid. Although the lipid content of forage crops is low, the total amount consumed by the ruminant may be considerable depending on the feeding system. Forage lipids contain high levels of unsaturated fatty acids such as linoleic acid which is a precursor for conjugated linoleic acid (CLA). Consumption of CLA isomers has been recognised as having a beneficial role in human health. Conjugated linoleic acid has been shown to inhibit carcinogens in experimental model studies, has antiatherogenic properties and alters energy metabolism by decreasing body fat and increasing lean tissues mass. In two experiments conducted at the Lethbridge Research Centre, finishing cattle were fed 6% (DM basis) sunflower oil in a barley-based diet (80% barley grain and 20% barley silage) for 70 and 100 d. Content of CLA in *longissimus* muscle (mg CLA per g lipid) was increased ($P < 0.05$) from 3.0 to 3.5 (17% over control) in the 70-day study and from 2.0 to 3.5 (75% over control) in the 100-day study. In a third experiment, in which cattle were fed 6% sunflower oil in a barley-based diet during both the backgrounding (30% barley grain and 70% pea hay; 112 d) and finishing periods (80% barley grain and 20% pea hay; 63 d), the CLA content in *bicep femoris* muscle increased ($P < 0.05$) from 2.1 to 14.8 (635% over control) mg CLA per g lipid. The data indicated that the use of forage in the feedlot diets results in significant increases in CLA content of ruminant meat.

AN AUTOMATED GAS PRODUCTION MEASURING SYSTEM TO ESTIMATE THE NUTRITIVE POTENTIAL OF FORAGES

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ABSTRACT

Fermentation kinetics of feedstuffs in rumen fluid can be studied by determining the undegraded residue after different periods of incubation in rumen fluid or using the nylon bag technique. However, the values for the early fermentation times are quantitatively very difficult to determine on the basis of substrate disappearance, mainly due to analytical constraints for recovering soluble matters and the significant contribution of inoculant and microbial mass to such small residue disappearance. In addition, both of these methods are laborious, expensive and difficult to standardize. An alternative method that allows evaluation of early fermentation is measuring gas production in a CO_2 saturated buffered rumen fluid. Since digestion of a feedstuff by ruminal microorganisms produces fermentation gases, gas measurements have been used to measure the extent and kinetics of fibre digestion *in vitro*. Gas produced in fermentation is generally proportional to net microbial metabolism and is therefore a possible end point for estimating digestibility. Good correlation between gas production (GP) measurements and *in vivo* measurements such as dry matter intake and digestibility has been reported. The main advantage of the GP technique is that it measures the appearance of metabolic products and thus reflects the "true" fermentation of feedstuffs. Recently, an automated gas production measuring system (AGPS) consisting of 64 gas-tight serum culture bottles, each connected to a pressure sensor and solenoid valve linked to a PC for continuous (real-time) monitoring of all serum bottles has been developed. The use of solenoid valves enables the AGPS to release overpressure and prevent gas accumulation and pressure build up in the serum bottles. The AGPS provides a reliable and rapid measurement of the extent and kinetics of forage and feedstuff digestion and can provide a powerful pre-screening tool prior to implementing more costly animal evaluation studies.

RUMINAL DEGRADABILITY OF MACERATED GRASS SILAGE

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ABSTRACT

Three forages (Orchardgrass (OG), Ryegrass (RG) and Tall Fescue (TF)) were harvested with either a conventional mower/conditioner or with a self-propelled macerator. The material was tedded and then chopped with a precision cut forage harvester. Approximately 4.5 kg of material was packed in duplicate mini-silos for each treatment/forage and capped with a bunsen valve and stored in a room maintained at 24°C for 42 days. The silos were then opened and pH determined on the silage. The remaining material was kept frozen at -20°C until analyzed. Due to inclement weather there was more variation across the 4 reps than was wanted in the dry matter of the material ensiled. The wettest material was 32.81 % dry matter while the driest was 39.31 % dry matter. The macerated material was significantly drier than the control material (36.93 vs. 33.90). OG was the driest, TF was intermediate while RG was the lowest. Each forage type was significantly different from the others (38.90, 34.48 and 32.90). The macerated material had a significantly higher pH than the control (4.28 vs. 4.24). The pH values for the three forages were all significantly different from one another (4.33, 4.12 and 4.25 for OG, RG and TF respectively). There was no difference in crude protein content between the macerated and control silage (12.46 and 12.21). TF had a significantly higher CP content than either OG or RG (13.40 vs. 11.88 or 11.71). The silages were tested for in situ disappearance from nylon bags. Six grams of silage dry matter (in the fresh form) were cut into approximately 2 cm length with a paper cutter and placed into large nylon bags. Each silage was incubated for 0, 2, 4, 6, 8, 12, 24, 48 and 96 hours in duplicate in two different cannulated cows maintained on a grass silage diet for. Degradability was calculated using the equations of Orskov and Macdonald, modified to include a lag phase. For dry matter degradability there was no effect of treatment on any of the parameters measured. RG had a significantly higher soluble dry matter fraction (DM) than either OG or TF (41.43 vs. 33.34 or 36.22). The rate of breakdown of the DM of RG silage was significantly faster than the TF silage (0.064 vs. 0.051) while OG was intermediate. The effective DM degradability of RG was also significantly higher than either OG or TF (70.25 vs. 61.67 or 63.46). The macerated silage had a significantly higher soluble N fraction than the control silage (23.41 vs. 20.97). There was no difference between any of the other treatment parameters. Ryegrass had a significantly higher soluble nitrogen fraction than either OG or TF (25.48 vs. 21.13 or 19.97). RG silage had the highest effective nitrogen degradability. In general it can be concluded that maceration had minimal effect on the nutrient content of the grass silages.

ROLE OF ANNUAL FORAGES IN RUMINANT FEEDING SYSTEMS

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ABSTRACT

Annual crops (primarily cereals) contribute significantly as forage feedstuffs in western Canada. Area of production depends on grain and beef cattle supply and demand cycles, as well as regional weather patterns. The objective of this presentation is to describe the role of annual relative to perennial forages in ruminant feeding systems from an economic and agronomic perspective. Reports written in the 1960's and 1990's indicated that prairie producers did not choose to increase perennial forage acreage. Therefore even during upturns in the cow cycle, annual forage filled a feedstuff gap. A recent review concluded that perennial stands lasted 5 years on average and were broken because of poor yield and weed invasion. Annual forages have been more stable for yield, particularly in dry years, but not necessarily more economical or land use efficient. Annual forages are used as conserved feed, pasture and residue forms. They add value to perennial forage-livestock systems when used effectively to enhance weed control, reduce winter feeding costs and to improve land use efficiency. In combination with perennial forages, annuals can provide flexibility for land use, time and labour management. When used ineffectively they are expensive relative to perennial forage systems. Thus, annual forages must be placed strategically to maximize added value as part of the entire crop-livestock system.

A REVIEW OF COMPENSATORY GAIN RESEARCH AND ITS APPLICATION TO FORAGE-BASED BEEF PRODUCTION SYSTEMS IN WESTERN CANADA

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ABSTRACT

Several factors, including the end of the Western Grain Trade Agreement (WGTA), an expanding beef sector, an abundance of fertilizer in the form of hog manure and the potential to produce excellent quality forage, have led many beef producers in Western Canada to add value to their calves prior to marketing through backgrounding programs. The economic benefit of this practice has been reinforced in a recent Western Canadian study which has demonstrated that backgrounding feeders to grass may provide an economic advantage over direct-finishing. As such, many producers wish to identify overwintering rates of gain which will realize the greatest economic return when animals are subsequently grazed in a management-intensive grazing system.

Considerable effort has been directed to understanding the phenomenon of compensatory gain under management conditions which are considerably different from those practiced in Western Canada. These differences in management include breed, age of cattle, nature of the overwintering and realimentation rations. Recent research conducted at the University of Nebraska has demonstrated that differences in days of restriction, degree of restriction and intake of NEg above maintenance resulted in a considerable variation (19-88%) in percent compensation achieved on native and tame grass pastures. As such, additional compensatory gain research which examines the management practices utilized in Western Canada, including the practice of overwintering spring/summer-born Continental-cross calves on 100% forage rations followed by a pasture phase on highly productive legume-based pastures, is required. This presentation will examine compensatory gain research conducted to date and will identify research needed to help facilitate the adoption of this economically important practice in Western Canadian beef operations.